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Engineering Investigation of Sewer Overflow Problem

Roanoke, Virginia

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ENGINEERING INVESTIGATION OF SEWER OVERFLOW PROBLEM

A Detailed Investigation Into the Cause and Effect of Sanitary Sewer Overflows and Recommended Remedial Measures for Roanoke, Virginia

by

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for the

FEDERAL WATER QUALITY ADMINISTRATION
DEPARTMENT OF THE INTERIOR

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ABSTRACT

Three study areas, representing approximately 2150 acres or 25 percent of the area served by the City of Roanoke, Virginia's separate sanitary sewerage system, were used in an analysis of stream pollution resulting from rainfall infiltration and sanitary sewer overflows.

Data from rainfall gauges were correlated with historical rainfall data to establish precipitation frequencies. Flows in the sanitary sewers and streams were gauged during storm events to measure infiltration and runoff quantities and to establish their relation to rainfall intensities and durations. Samples were obtained during storm events to assess the quality of sewer overflows and storm runoff.

A computer program was developed to permit the analysis of the sewerage system under various rainfall frequencies and durations, to calculate the overflow quantities discharged to the watercourses and to assess the sewer overflow problem for the entire urban area.

Rates of infiltration in the sanitary sewers were found to be as high as 24,000 gallons per inch of pipe diameter per mile per day which produced overflows from a single storm event equivalent to 14 percent of the daily untreated sewage.

Various remedial measures were investigated and a program, based primarily on reducing infiltration by at least 80 percent, was presented. The cost would be about $61 per capita.

This report was submitted in fulfillment of Contract Number 14-12-200 between the Federal Water Quality Administration and the architectural and engineering firm of Hayes, Seay, Mattern & Mattern, Roanoke, Virginia.

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SECTION 1

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

1. It is now well established that overflows from combined sewers constitute a significant part of the nation's total water pollution problem. The separation of sanitary and storm sewers has been considered to be the ultimate solution for the elimination of such overflows. However, the mere fact that the systems are separated does not necessarily reduce the number or pollutional effect of overflows. Separate sanitary sewers can act as combined sewers due to the excessive infiltration of surface runoff and produce overflows of untreated sewage.

2. This study was conducted on 25 percent of Roanoke, Virginia's separate sanitary sewerage system which is probably representative of most existing separate sanitary sewerage systems installed prior to 1950. The study revealed that overflows from this separate system amount to one to two percent of the annual average untreated sewage. Overflows are even more significant on an individual storm basis, amounting to as much as 14 percent of the daily untreated sewage.

3. Overflows from sanitary sewers are not controlled; therefore, they occur indiscriminately throughout the watershed causing additional health and safety problems. Overflowing manholes in streets and residential property and flooded basements are esthetically objectionable as well as potential health hazards and should be eliminated.

4. All sanitary sewer overflows are not directly into a stream or water course. Only 25 percent of the pollution from such overflows could be actually traced to entering a stream. The remainder either re-entered the sewer after the storm, ponded, or entered the ground water table. However, the possibility of some of the pollutants reaching the stream through undetected leaks or through ground water cannot be ruled out.

5. The greatest cause of the sewer overflows is excessive infiltration. During storms sanitary sewers become, in effect, storm sewers due to the numerous entry points for surface runoff. Contrary to original beliefs, relatively few downspouts and storm drains were directly connected to the sanitary sewers.

6. Storm water entry points ranged from perforated manhole covers to broken pipe sections exposed to surface stream flow. Crushed pipe resulting from other types of construction operations, broken service laterals, and service laterals poorly connected to the sewer main were other major sources of infiltration.

7. No logical relationship could be found between the topographical characteristics of the drainage area and the rates of infiltration or number and type of points of infiltration.

8. Flow hydrographs indicated that peaks in the sanitary sewers occurred simultaneously with those in the storm sewers. A rainfall intensity of 0.04 inch in 1 hour was required to cause measurable infiltration.

9. Throughout the range of storms monitored, the average rate of infiltration was proportional to the average rainfall intensity, as shown on Figure 19; thus, the higher the rainfall intensity the higher the rate of infiltration. Rates of infiltration as high as 24,000 gallons per inch of pipe diameter per mile per day were recorded, which is 50 to 100 times the normally specified allowable amount.

10. Total volumes of overflow and infiltration for any particular rainfall event are a function of storm duration and average rainfall intensity. Average rainfall intensities greater than 0.4 inch per hour generally have durations of less than two hours.

11. Many municipalities rate the capacity of the interceptor sewer as a multiple of the average dry weather flow. Capacity allowances on such a basis have no relation to the actual problem other than merely providing some excess. Rather, capacity allowances for infiltration in the design of interceptor or trunk sewers should be based on the total length of upstream sewer.

12. In addition to localized overflows from the sewerage system, overflows occur at the Water Pollution Control Plant on the average of 10 times per year. This overflow contributes as much as 27 percent of the total pounds of untreated BOD as a result of a single storm event. When added to the overflow from the sanitary sewer, the total overflows contribute 43 percent of the daily untreated BOD.

13. About 77 percent of the total annual overflows occur between May and October, and constitute about 75 percent of the total overflow volume. This corresponds to the period of lowest stream flows, and the peak recreational water use season when water pollution would be the most critical.

14. Higher than normal river flows cannot be relied upon for dilution of the overflows. Localized thunderstorms produce sewer overflows without significantly affecting the flow of the river.

15. While no in-depth study was made on the pollutional potential of storm surface runoff, the associated data indicated that its quality was similar to that of secondary treated effluent. This storm runoff increased the BOD concentrations in the streams three to five times over that of normal dry weather flow. Considering the volumes of storm runoff and its quality, the amount of BOD contributed to the Roanoke River from storm runoff alone could easily be 200 percent of that of the sewer overflows. Therefore, it appears that pollutional effects of storm runoff are appreciable and clearly point to the need for better housekeeping practices in our urban watersheds. A more detailed analysis may indicate a need for treatment of urban runoff. At any rate our small urban streams can no longer be given the traditional "backdoor" approach and treated as conveyors for our refuse.

16. Due to the losses of untreated sewage through overflows, the effectiveness of pollution control cannot be gauged solely by the efficiency of a treatment process. The installation of tertiary treatment facilities to remove additional fractions of pollutants appears unwarranted when large volumes of the sewage are lost through overflows and never reach the treatment process. Therefore, the entire "system", including lines and treatment plant, should be evaluated as a whole.

17. It is concluded that a reduction of pollution from sewer overflows in Roanoke can best be obtained by a combination of remedial measures. These measures include more complete sewer separation, replacement of critical lines to increase capacity, detention of peak flows within the drainage basin, controlled release based on the system's downstream capacity, and treatment of all flows at the Water Pollution Control Plant. The key is the reduction of infiltration by separation or elimination of storm surface entry points, utilizing the computer to achieve optimum designs of the system.

18. The possibility of removing all storm water from existing sanitary sewerage systems, especially older ones, is remote. However, it is believed that as much as 80 percent could be eliminated through a program of inspection and repair. The total estimated cost of such a program is $61 per capita; far below the cost of complete line replacement.

19. The use of the computer permits evaluation and optimum selection of detention basin size and location and pipe capacities under a variety of trial conditions and storm events. Unfortunately, a considerable amount of data is required on the existing sewerage system, much of which must be determined in the field as it is often not available from office records.

20. The detention basins selected will detain the overflow for treatment during off peak periods from at least 90 percent of the storm events causing overflows in a five-year period; this corresponds to 90 percent of the overflow volume during the same period.

RECOMMENDATIONS

1. Further sewer separation is essential and it is recommended that an intensive inspection and repair program be undertaken on a selected drainage area basis, employing the type of program outlined in this report.

2. Sewer joint sealing procedures are not new, but there are many sealing materials which are unproven. It is recommended that the repair program for the initial drainage basin selected, Murray Run, be developed as a demonstration project to evaluate the materials, methods, and effectiveness of the overall program. This demonstration area will lay the groundwork and supply much needed information for future improvements to the remainder of the City's sanitary sewer system.

3. A significant amount of infiltration originates from storm water inlet points on private property, through either illegal connections or breaks. The City's program should provide for a cooperative arrangement between the private owner and the City for these repairs and separation of storm water. This could be established through uniform charges for such work or by licensed contractors with established rates.

4. A sewer leak detection program is of little value if results are not properly recorded and acted upon. The results of a leak survey should be promptly evaluated and action taken. Private owners of property with violations or deficiencies should be promptly notified and periodic follow ups made to insure corrections have been made.

5. Pollution from overflows at the pollution control plant can be reduced by in-house changes in process piping. It is recommended that digester supernatant and sludge thickner overflow piping be revised so that they return to a point other than the overflow manhole; thus, these extra pollutants are not flushed into the river during storms.

6. It is recommended that more study be directed to the impact of the pollutional effects of urban storm surface runoff. Such studies would relate detrimental effects of storm runoff to other known sources of potential pollution and develop any recommendations for reducing pollution from this source.

7. Studies involving stream and sewage flow measurements, rainfall measurements, and sampling require equipment that often is not readily available. It is, therefore, recommended that the allowance for initial start-up time for such studies be a period of three to six months. Further, such studies are dependent upon weather for the gathering of data; therefore, the time frame should be flexible to insure a representative season has been observed.

SECTION 2

INTRODUCTION

The overflow of untreated sewage from sewers has long been recognized as one of the major contributors to the pollution of watercourses in this country. In cities with combined storm and sanitary sewer systems, the sewers overflow during rainfalls when the combined storm water and sewage flow is greater than the hydraulic capacity of the system. Where the overflows have been large and occurred frequently, the quality of waters which received the overflow have deteriorated badly. In some instances the waters have lost their recreational value completely.

The recognition of sewage overflow as a major pollutional problem has prompted extensive investigations and studies aimed at finding economical methods of solving the problem. Commonly accepted practice is to separate the combined sewer system so that the storm water and the sanitary sewage are conveyed in separate lines and theoretically do not become mixed. Experience with separate systems, however, has shown that they do not entirely eliminate the sewer overflow problem. Storm water infiltration in the separate sanitary sewers has become a formidable problem for many cities. The increase in flow in sanitary sewers caused by the infiltration of storm water not only results in frequent sewage overflows in sewer lines but also causes occasional overloading of the sewage treatment facilities. A study conducted in Johnson County, Kansas and Kansas City, Missouri and published in 1965 indicates that during periods of moderate rainfall the major portions of the flow in the sanitary sewers were from sources other than water-using plumbing fixtures (1). [1]

A study of Roanoke, Virginia's separate sanitary sewer system conducted in 1965 revealed that storm water infiltration in the system was a serious problem (2). The report concluded that overflows from the sanitary sewers were resulting in unsightly and undesirable pollution of the watercourses in the City. The study also reported that peak wet weather flows in the sanitary sewers exceeded the capacity of the Water Pollution Control Plant, causing raw sewage to be bypassed to the Roanoke River. The plant is located approximately 10 miles upstream from Smith Mountain Lake which is used extensively for recreational purposes.

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[1] Numerals in parentheses refer to corresponding items in Section 8 - References.

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PURPOSE

The purpose of this study was to investigate the sanitary sewer overflow problem in Roanoke, Virginia and to recommend feasible remedial measures to abate the sewer overflows. In addition, it is intended that the study establish a basis for the evaluation of the benefits and economics of alternate methods of controlling water pollution from the sewage overflows.

SCOPE OF PROJECT

In order to provide the basic data required to completely assess and evaluate the sanitary sewer overflow problem in Roanoke, it was deemed necessary to conduct detailed field and hydrological investigations, gauge flows in streams and sewers, and determine water quality by sampling and testing. The study was limited to 25 percent of the existing sanitary sewer system. Three study areas. determined to be generally representative of other areas within the entire city, were selected as the models for the detailed investigations.

The study was begun in September 1968 and covered a time span of 15 months, at a budgeted cost of $114,000. The study areas contained 348,000 lineal feet of sewer, 2150 acres of land and 27,000 people.

The field investigation consisted of smoke testing the sanitary sewers, manhole cover surveys, and other field observations necessary to determine the condition of the existing sewers and to locate storm water entry points. The hydrological investigation included measuring rainfalls during the study period 6 February 1969 through 5 August 1969. The gauging consisted of measuring flow in the streams and sewers of the study areas and gauging of the bypass line at the Water Pollution Control Plant. The water sampling and testing phase of the study consisted of sampling the flows in the streams and sewers in the study areas, sampling the bypass sewage flow at the Water Pollution Control Plant, and analyzing the samples to determine quantities of various pollutional constituents. The sampling and water quality analysis reflected both wet weather and dry weather flows.

Evaluation and analysis of the flow gauging and rainfall data were required to determine the effect of storm water infiltration on sewage flows and to estimate the frequency of overflows in the study areas and at the Water Pollution Control Plant. The results of the water quality and testing data served as a basis for assessing the pollutional effect of the estimated overflows.

The study also includes the investigation of the application of existing and new technology to the abatement of the overflow problem. From the assessment of the sewer overflow problem, a program of remedial measures is presented together with cost estimates which permit evaluation of the effort to be applied towards reducing overflows.

SECTION 3

STUDY AREAS

Roanoke, Virginia lies in the Appalachian Highlands, a system of mountains, hills and valleys running generally in a northeasterly-southwesterly direction from New England to Alabama. The City of Roanoke, as shown on Plate 1, is located in one of a series of valleys situated just west of the Blue Ridge Mountains. Because of the Roanoke Valley's location, runoff from rainfall travels fairly rapidly to the many streams originating in the higher elevations surrounding the area.

Roanoke's topographic situation modifies the climatic picture in comparison to adjacent areas. Because of its location, with the Allegheny Mountains to the west and the Blue Ridge Mountains to the east, Roanoke is afforded some protection from extreme high temperatures in the summer and extreme low temperatures in the winter. However, the weather is quite variable, even though the extremes are rare.

Precipitation is fairly well distributed throughout the year with a slightly higher amount during the warmest months. The yearly average is about 34 inches. Droughts are uncommon as are rainy spells of long duration.

The Roanoke Valley is drained by the Roanoke River and many small tributaries. The river begins in the mountain ranges to the west of Roanoke and flows in a southeasterly direction before depositing its flow into Albemarle Sound. Most of the City of Roanoke is safe from flood danger, although a portion of the central business district is occasionally flooded.

The strata underlying Roanoke is composed primarily of shale, sandstone and limestone rocks. Steep slopes occur widely throughout the valley with about 20 percent of the land area having slopes of 20 percent or greater. Such slopes are not usable for most urban purposes. Soils are also quite variable in their distribution since they are strongly conditioned by the bedrock and slope. Water that penetrates the ground surface percolates through the soil to the impervious layers of rock below. The water then proceeds along the rock layers until it comes to a rock outcrop on the surface, or percolates deeper into the ground through crevices, thus adding to the water table, or generally flows toward streams and rivers. In predominantly limestone areas in the valley, the movement of the water underground has eroded subsurface channels over a period of time and in some cases large underground rivers and streams have resulted from this movement.

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The quantity of runoff from a rainfall event is generally related to an area's land use. The following tabulation shows the land use distribution within suburban Roanoke and the City of Roanoke.

LAND USE DISTRUIBUTION (3)

Land Use Classification	Suburban Roanoke Area, acres	Suburban Roanoke Percent of Developed Land	City Area, acres	City Percent of Developed Land
Residential	14,346	36	5,483	48
Commercial and Institutional	2,854	7	820	7
Industrial	1,300	3	717	6
Public	12,628	33	1,391	12
Transportion	8,458	21	3,051	27
Total Developed	39,586	100	11,462	100
Vacant Land	91,802		5,294	
Total	131,388		16,756	

From the land use table, the areas having medium to high coefficients of runoff constitute approximately 31 percent of suburban Roanoke's total developed land area and 40 percent of the City's. Those areas having medium to low coefficients of runoff constitute about 69 percent of the suburb's total developed land and 60 percent of the City's.

The existing sewerage system was constructed over a period of many years and in many instances predates the keeping of accurate records. Up until 1951 the system was comprised of numerous trunk mains leading from the sewage collection systems and discharging directly into the Roanoke River, which flows west to east, and Tinker Creek, which flows north to south. The interceptor system was built in 1951 and conveys the wastes to the Water Pollution Control Plant constructed near the east corporate limits on the Roanoke River.

The present system of interceptors and trunk sewers contains approximately 40 miles of pipeline and serves not only the City of Roanoke, but also the City of Salem and suburban areas in adjacent Roanoke County. The system is separated from the storm sewers except for a very small area of combined sewers near the business district of Roanoke. A general layout of the existing interceptor and trunk sewers is shown on Plate 1.

The scope of this study provided that only 25 percent of the City's sanitary sewer system would be investigated and the results would be extrapolated to include the entire City sanitary sewer system. Three separate drainage areas were selected as being representative of the entire City's system. The areas selected had the following similar characteristics.

1. A major trunk or interceptor sewer
2. Area drained by a well defined stream
3. A well defined boundary with the sanitary sewered portion of the area lying completely within the City

The following is a discussion of the characteristics of the study areas relative to land development, storm surface runoff, storm water infiltration into the sanitary sewers and general condition of the interceptor and collector system.

MURRAY RUN

The Murray Run stream drainage area is an 1818-acre tract of land lying partly in the City of Roanoke and partly in Roanoke County. The sewered portion within the City contains 909 acres. Plate 1 shows a layout of the Murray Run interceptor in relation to the City's entire interceptor system. There are approximately 95,000 feet of sewer, ranging in size from 6- to 15-inch, serving about 6000 persons. The remaining 909 acres in the County are without sewers at present; however, there are plans to extend lines beyond the City Limits in the near future.

The portion of the stream drainage area in the County is very similar to its sewered counterpart in the City except it is presently not as densely developed. Contained within its boundaries at present are a golf course, a school, medium to high priced single family dwellings and scattered small commercial establishments. A large shopping center is scheduled to be completed in the near future.

Land use in the sanitary sewered portion of the Murray Run study area, as shown on Plate 2, is summarized as follows:

Land Use	Area, acres
Residential	635
Commercial	38
Industrial	0
Office and Institutional	32
Open Area	204
Total	909

Residential use, comprising 70 percent of the sewered portion of the study area, is predominantly single family dwellings ranging in age from new to 30 years and in value from $20,000 to $80,000. The houses are generally brick or frame and in good to excellent condition.

With the exception of one large regional shopping center, the commercial land use in the sewered area consists of small business establishments scattered along the major streets. Commercial use comprises approximately 4 percent of the total sewered area.

There are four schools within the sewered area, three elementary and a large high school. These schools account for the major portion of office and institutional land use. Three large parks, containing a total of 204 acres, are the only large open areas.

The top cover of the three parks consists primarily of woods, light underbrush and grass. The only paved areas in the parks are tennis courts and some parking areas. A breakdown of top cover characteristics of the sanitary sewered portion of Murray Run is as follows:

Top Cover	Area, acres
Roof Area	59
Street and Parking Area	87
Wooded Area	242
Open and Grassed Area	521
Total	909

24TH STREET

The 24th Street stream and sewer drainage areas lie wholly within the corporate limits. The 24th Street interceptor and its relation to the City's entire interceptor system are shown on Plate 1. The study area contains approximately 93,000 feet of interceptor and collector sewer ranging in size from 6- to 15-inch.

The area is basically urban, containing a land use mixture of residential, commercial, industrial, office and institutional and open areas. Its present population is approximately 10,000 persons. Development of the 1034-acre area commenced around 1900 and has progressed until there is presently very little developable land remaining. The overall density of the present development is approximately 1.1 buildings per acre.

The land use in the 24th Street study area as shown on Plate 2, is summarized as follows:

Land Use	Area, acres
Residential	536
Commercial	47
Industrial	181
Office and Institutional	14
Open Area	256
Total	1034

With the exception of one public housing development, which occupies approximately 3 acres, the residential use is primarily single family dwellings. The majority of the dwellings are in fair to good condition and range in value from $10,000 to $30,000. These dwellings, both brick and frame, were built from about 1910 to the present. A few older homes in one portion are in poor condition and are of little value.

The commercial development is generally single story, light construction type.

The industrial land use consists primarily of light manufacturing establishments. These businesses are concentrated near the railroad in the southern portion of the study area.

Three schools account for nearly all of the 14 acres of office and institutional land use. A 124-acre country club and an 87-acre cemetery constitute a portion of the grassed land.

The top cover characteristics of the 24th Street study area are as follows:

Top Cover	Area, acres
Roof Area	65
Street and Parking Area	112
Wooded Area	0
Open and Grassed Area	857
Total	1034

TROUT RUN

The Trout Run study area is a 997-acre tract of land lying wholly within the boundaries of the City of Roanoke. Plate 1 shows a layout of the Trout Run interceptor in relation to the City's entire interceptor system. The 160,000 feet of sewer line ranges in size from 4- to 12-inch and serves approximately 11,000 persons. The area is completely developed in a manner typical of the older urban areas throughout the United States. The streets form a grid pattern with each block containing approximately 3 acres of land. The development is dense, approximately 3 buildings per acre of land, and is a mixture of small industrial buildings, commercial establishments, offices, schools and houses.

The development of the area began around 1900 and has continued to the present. Many of the older buildings have not been maintained adequately and are in a dilapidated condition.

The land use in the Trout Run study area, as shown on Plate 2, is summarized as follows:

Land Use	Area, acres
Residential	589
Commercial	67
Industrial	260
Office and Institutional	18
Open Area	63
Total	997

With the exception of some industrial land use which is concentrated in the southern portion of the area along the railroad, the above uses are found scattered throughout the area.

Residential use, comprising about 59 percent of the total area, is predominantly single family dwelling units. Approximately half of the dwellings are old and in very poor condition. These are typically one and two story frame, closely spaced, ranging in value from $1,000 to $7,500. The remaining 50 percent of the dwellings are in better condition and are a mixture of brick and frame, ranging in value from $6,000 to $15,000.

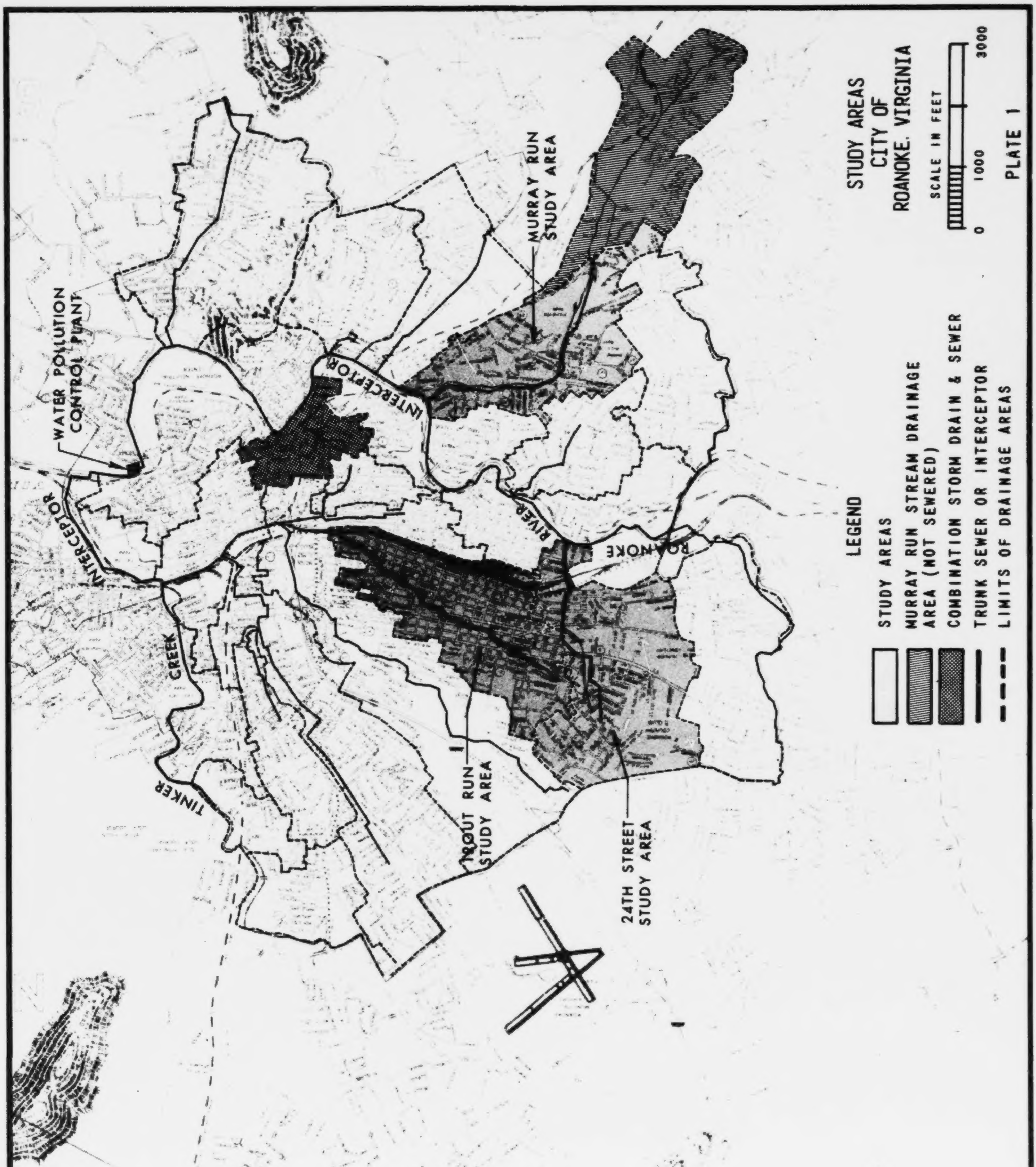
The commercial land use in the area is varied, ranging from small neighborhood service stations and grocery stores to large wholesale distributors. It comprises slightly less than 7 percent of the entire study area.

The 260 acres of land devoted to industrial use constitutes approximately 26 percent of the total drainage area. Included in the 260 acres are 122 acres of railroad right-of-way. The remaining 138 acres are devoted to a variety of light industrial uses such as bakeries, bottling works and equipment fabrication.

Four schools in the area occupy the major portion of the 18 acres of office and institutional land in the area. The only large open areas in the study area are two parks, Eureka and Melrose. The parks, together with vacant lots scattered throughout the area, account for 63 acres of open land.

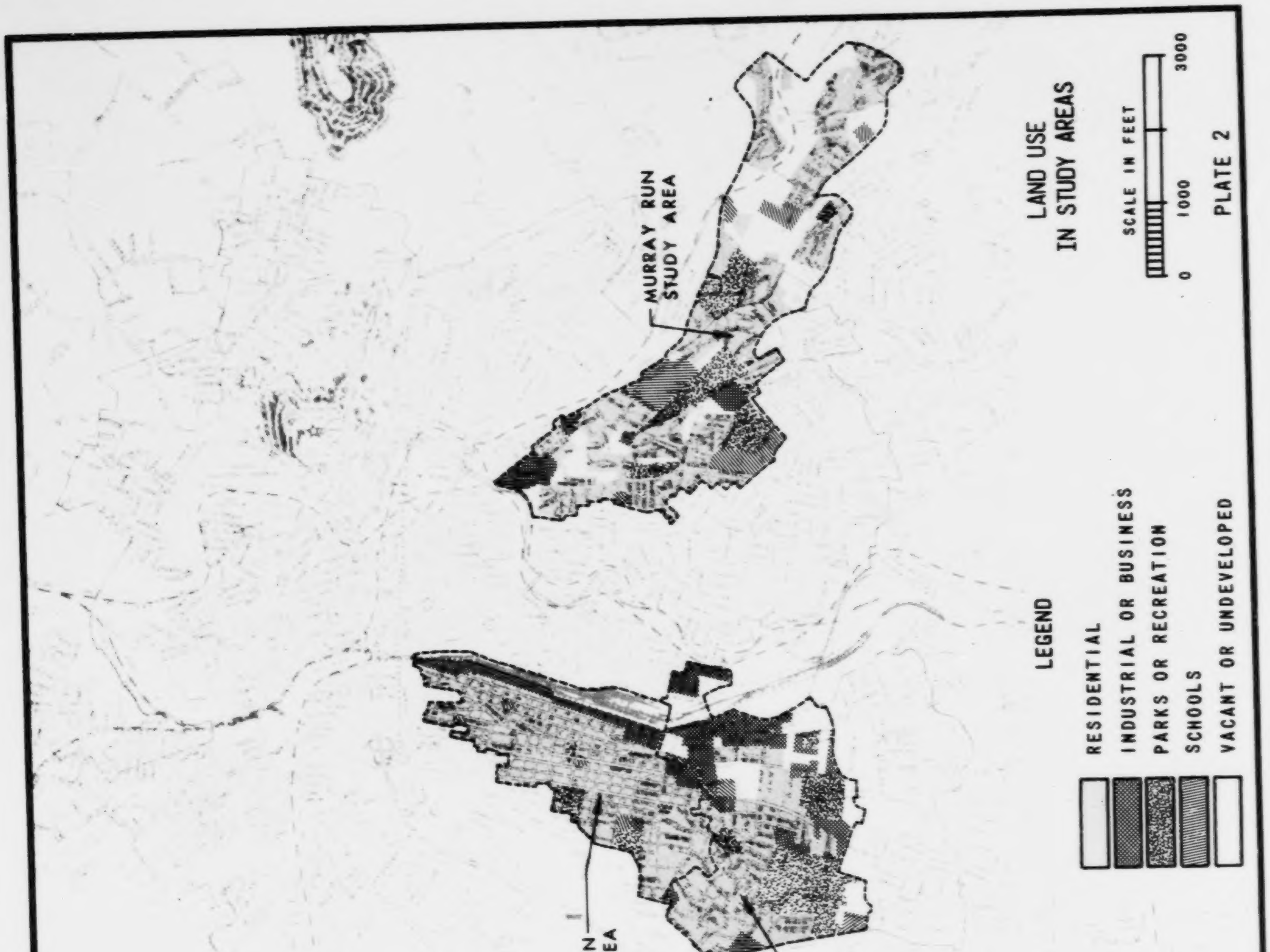
The streets are paved and some have curb and gutter. A breakdown of top cover characteristics by acreage is as follows:

Top Cover	Area, acres
Roof Area	135
Street and Parking Area	160
Wooded Area	0
Open and Grass Area	580
Railroad	122
Total	997


WATER POLLUTION CONTROL PLANT
INTERCEPTOR
INTERCEPTOR
MURRAY RUN STUDY AREA
TROUT RUN STUDY AREA
24TH STREET STUDY AREA
TINKER CREEK
ROANOKE RIVER
LEGEND
STUDY AREAS
MURRAY RUN STREAM DRAINAGE AREA (NOT SEWERED)
COMBINATION STORM DRAIN & SEWER
TRUNK SEWER OR INTERCEPTOR
LIMITS OF DRAINAGE AREAS
SCALE IN FEET
0
1000
3000

STUDY AREAS
CITY OF
ROANOKE, VIRGINIA

PLATE 1


MURRAY RUN STUDY AREA
TROUT RUN STUDY AREA
24TH STREET STUDY AREA
LEGEND
RESIDENTIAL
INDUSTRIAL OR BUSINESS
PARKS OR RECREATION
SCHOOLS
VACANT OR UNDEVELOPED
SCALE IN FEET
0
1000
3000

LAND USE IN STUDY AREAS

PLATE 2

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SECTION 4

RESULTS OF INVESTIGATION

FIELD INVESTIGATION

The field investigation, undertaken in each of the three study areas to assess the condition of the sanitary sewers and to locate sources of storm water infiltration, consisted of smoke testing the entire sanitary sewer system, photographic inspection of clogged lines, a manhole cover survey and various field observations.

The technique of smoke testing was used to locate points for surface water entry into the sanitary sewers and to locate cross-connections between storm water drains and the sanitary sewer system. The smoke testing was conducted by the City of Roanoke under the supervision of Hayes, Seay, Mattern and Mattern. The manhole cover survey was undertaken to locate manholes with perforated covers in low lying areas which, when flooded, could be expected to act as storm water inlets to sanitary sewers.

A total of 509 points of entry of storm water infiltration were located in the three study areas as a result of the manhole cover survey and smoke testing. A breakdown of these entry points is given by type and drainage area in Table 1. The table shows that a major portion of the entry points are simply leaks in the sanitary sewer system. The vast majority of the leaks detected were in collector sewers and house laterals. Nine of the leaks, three in the Murray Run study area and six in the 24th Street study area, were observed to be exposed to stream flow during periods of wet weather and some during dry weather flow. These leaks can be expected to be major contributors of storm water infiltration. A leak of this type, discovered in the 24th Street study area, is shown in Figure 1.

The smoke testing revealed only 33 cross-connections between storm water drains and the sanitary sewers, 27 of which were in the Trout Run study area. All of these were roof drains connected directly to sanitary collector sewers. Smoke was observed emitting from 58 curb inlets which were initially thought to be directly connected to the sanitary sewer system. Further investigation, however, revealed that none of the inlets were directly connected to the sanitary sewers. It was determined that the smoke reached the inlets by filtering from leaks in the sanitary sewers into cracks in the nearby storm sewer, and subsequently into the curb inlets.

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Photographic inspection of the Murray Run interceptor sewer revealed that root masses had penetrated the pipe joints and formed large obstructions in the line as shown in Figures 2 and 3. The roots severely limit the capacity of the line to carry flows in excess of normal dry weather sewage flow. These root conditions were not observed to exist in the Trout Run and 24th Street interceptor lines. It was found, however, that peak dry weather flow periodically exceeds the capacity of the Trout Run interceptor and overflows into the stream, as shown in Figure 4.

TABLE 1

TABULATION OF POINTS OF ENTRY
OF STORM WATER INFILTRATION

	Study Area		
Type of Entry Point	Murray Run	Trout Run	24th Street
Leaks in Sanitary Sewer Exposed To Surface Runoff	111	201	63
Leaks in Sanitary Sewer Exposed To Stream Flow	3	0	6
Leaky Manholes	3	0	0
Roof Drains Connected To Sanitary Sewer	5	27	1
Manholes with Perforated Covers In Areas Subject to Ponding	27	45	17
Totals	149	273	87

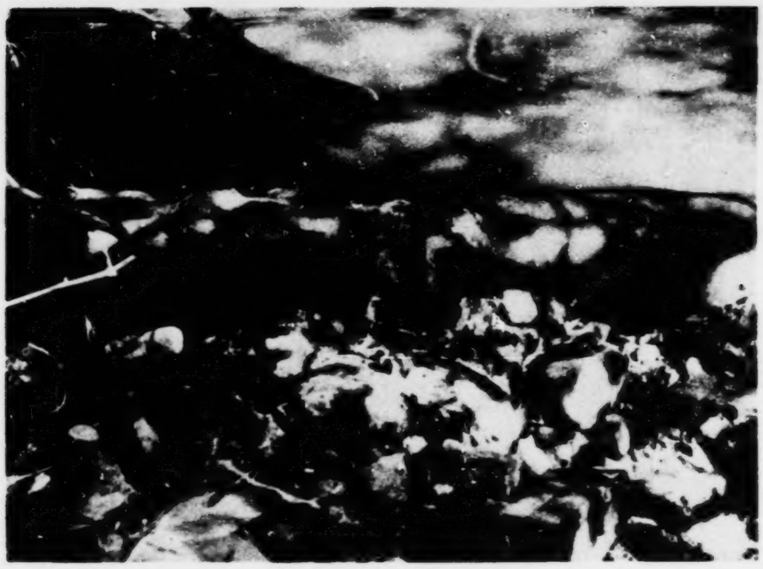


Figure 1. Open Joint of Pipe in 24th Street Interceptor

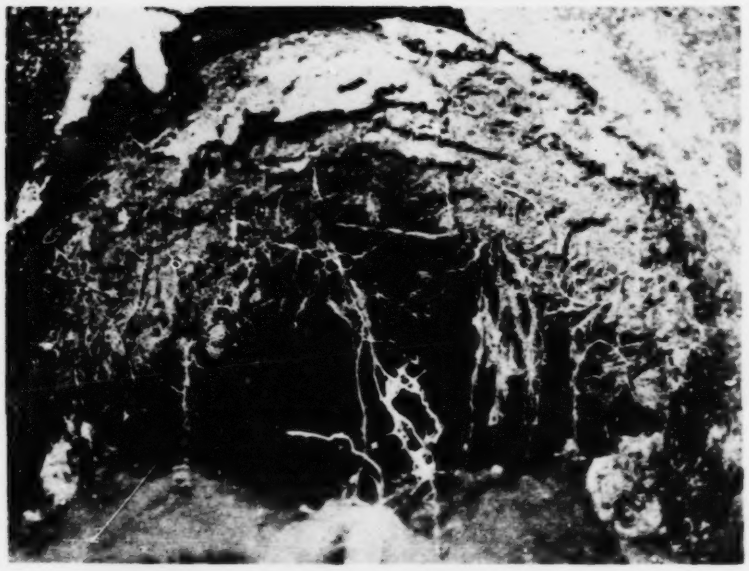


Figure 2. Roots in Murray Run Interceptor

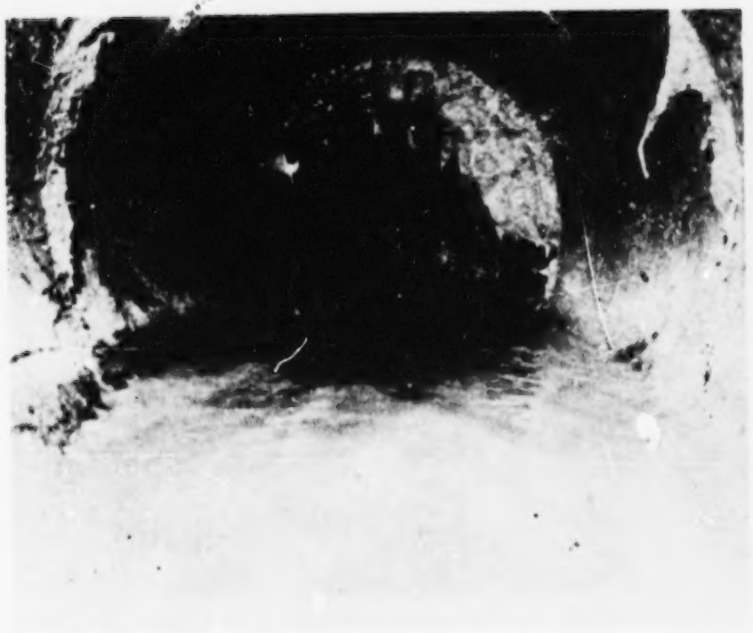


Figure 3. Roots in Murray Run Interceptor

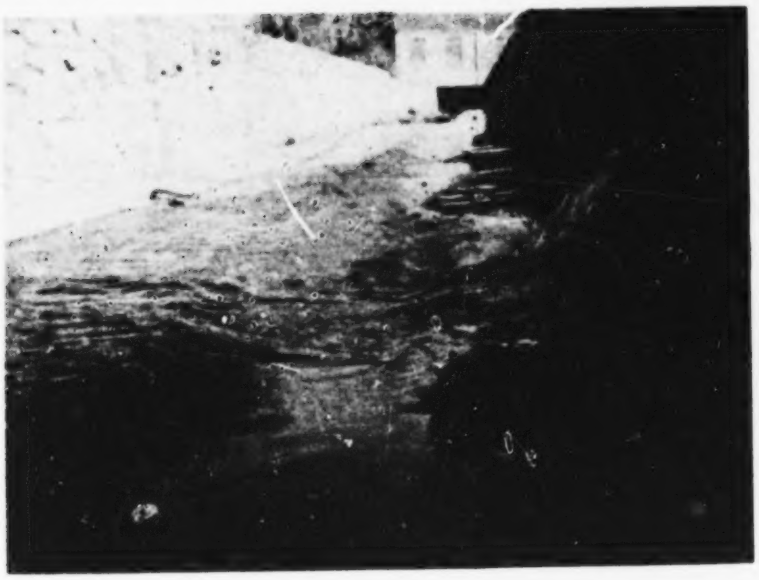


Figure 4. Overflow in Trout Run Study Area

RAINFALL INVESTIGATION

Rainfalls were measured in each of the three study areas during the study period 6 February 1969 through 5 August 1969 by means of rain gauges installed at locations shown on Plates 3 through 5. The gauge shown in Figure 5, installed in the Murray Run study area, was a recording type gauge which provided graphs of accumulated rainfall versus time. The gauges in the Trout Run and 24th Street areas were the non-recording type, useful only in recording the total amount of rainfall.

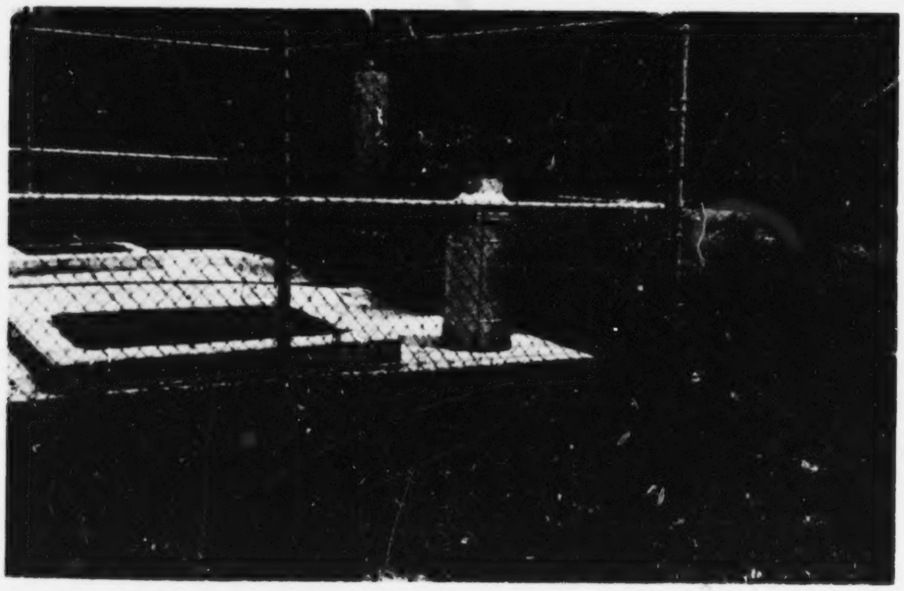


Figure 5. Recording Rain Gauge
in Murray Run Study Area

A tabulation of the characteristics of the major rainfall events is given in Table 2. A plot of the relationship between rainfall intensity and time is shown for these storms in Figures 34 through 88 in Appendix VI.

GAUGING STREAMS AND SEWERS

Flows in the streams and the sanitary sewer interceptors were gauged in each of the three study areas during each major rainfall event and during dry weather. The gauging techniques employed were selected to be compatible with the physical characteristics of the streams and sewers. Water level recorders, where used, were calibrated to record depth of flow. A limited number of water level recorders precluded the measurements of all streams and sewers during all rainfall events. Recorders were relocated periodically between study areas and the Water Pollution Control Plant.

MURRAY RUN STUDY AREA

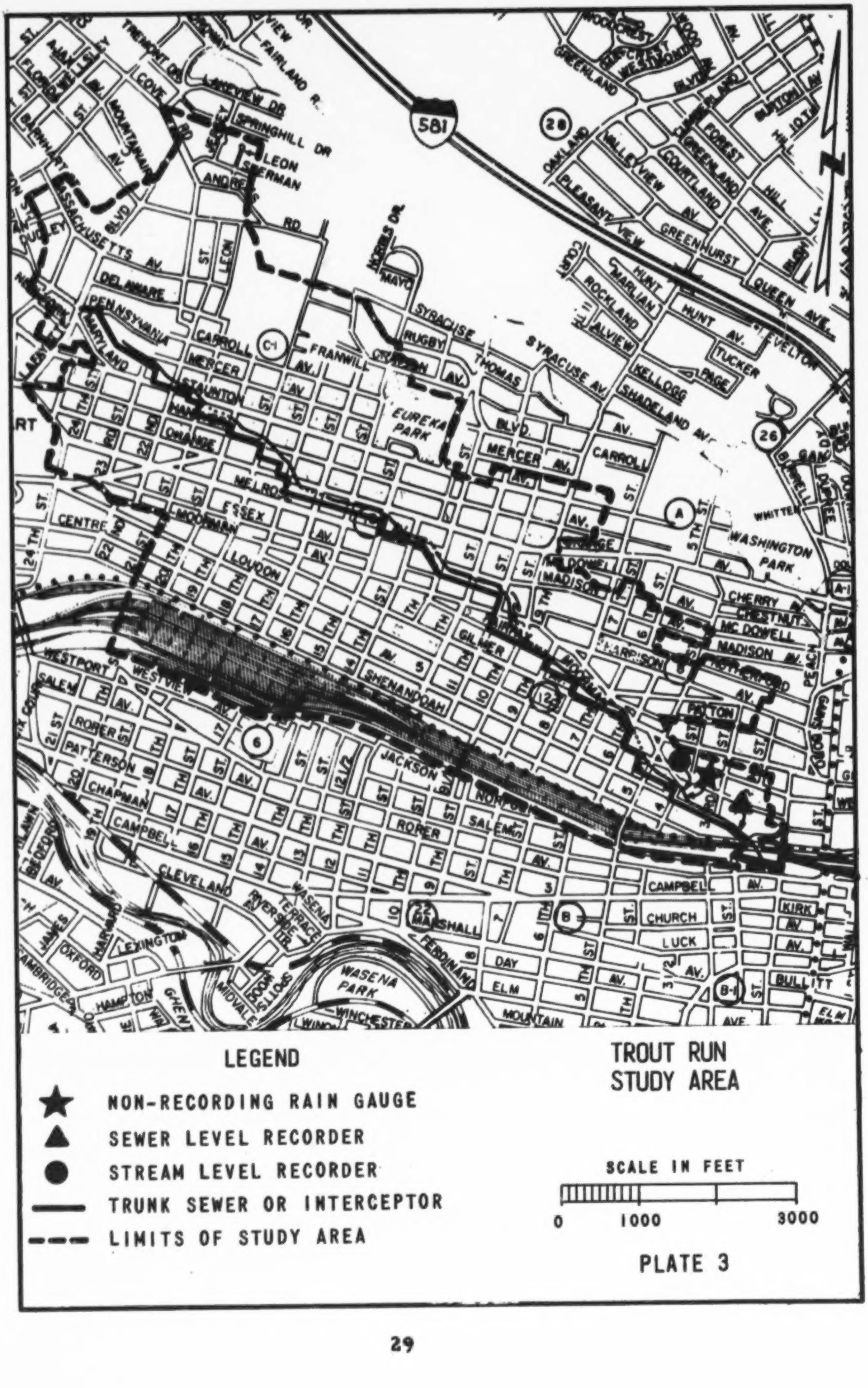
The gauging technique employed in the Murray Run stream involved continuous recording of the depth of flow in the stream along a section where the slope of the stream bed was constant and the flow was uniform. The depth of flow was monitored by a continuous water level recorder installed above a stilling basin as shown in Figure 6. The installation was located in the lower reaches of the study area as shown on Plate 5. A stage-discharge curve was developed from the Manning Formula using the measured hydraulic characteristics of the stream. The stage-discharge curve was then used to estimate stream flow based on depth measurements. This curve is included in Appendix VI as Figure 95.

The gauging technique used in the Murray Run sanitary sewer interceptor was basically the same as that used in the stream. Due to the root masses, the hydraulic characteristics of the sewer when flowing over 1/2 full could not be determined so that gauged flows could not be correlated with calculated flows. A weir was installed to permit overflows to be gauged after the sewer became surcharged. The sewer was essentially surcharged when the depth of flow reach 0.6 foot. Thus, the gauge recorded all flows up to this depth and all overflows over the weir.

TROUT RUN STUDY AREA

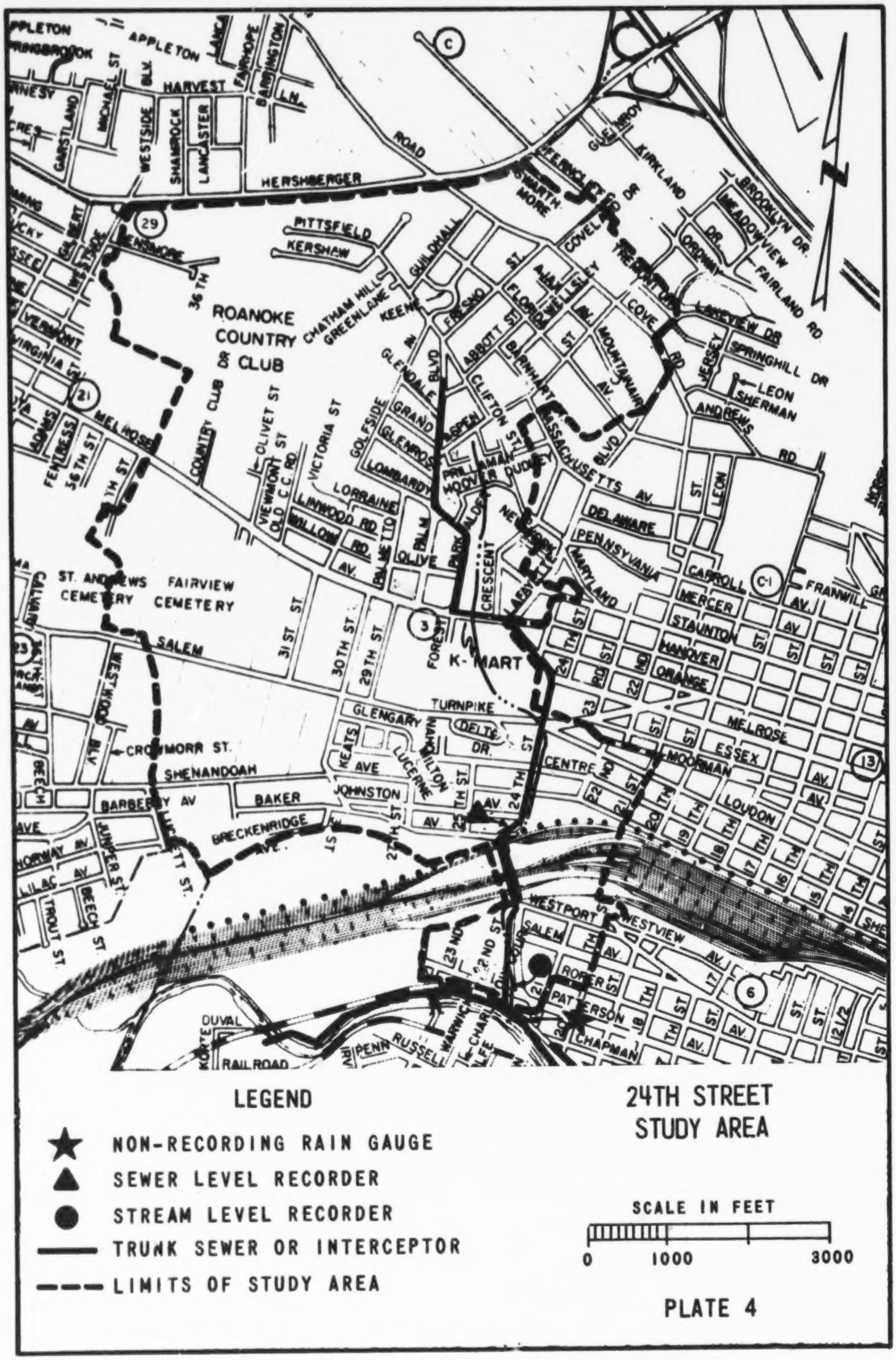
The gauging installation used in the Trout Run stream, shown on Figure 8, consisted of a water level recorder which monitored the depth of flow above a sharp-crested weir. The location of the recorder within the study area is shown on Plate 3. The stage discharge curve used to convert the measurements of depth above the weir to stream flows is included as Figure 96 in Appendix VI.

A water level recorder was installed as shown in Figure 9 to monitor the depth of flow in the Trout Run interceptor sewer. A stage-discharge curve based on the Manning Formula and the measured hydraulic characteristics of the sewer were used to convert the depth measurements to flow estimates. The stage-discharge curve is included as Figure 99 in Appendix VI.


LEGEND
★ NON-RECORDING RAIN GAUGE
▲ SEWER LEVEL RECORDER
● STREAM LEVEL RECORDER
TRUNK SEWER OR INTERCEPTOR
LIMITS OF STUDY AREA
SCALE IN FEET
0
1000
3000
581
EUREKA PARK
WASHINGTON PARK
WASENA PARK

TROUT RUN
STUDY AREA

PLATE 3


LEGEND
NON-RECORDING RAIN GAUGE
SEWER LEVEL RECORDER
STREAM LEVEL RECORDER
TRUNK SEWER OR INTERCEPTOR
LIMITS OF STUDY AREA
SCALE IN FEET
0
1000
3000
APPLETON
HARVEST
HERSHBERGER
ROAD
PITTSFIELD
KERSHAW
ROANOKE COUNTRY CLUB
COUNTRY CLUB DR
MELROSE
ST. ANDREWS CEMETERY
FAIRVIEW CEMETERY
SALEM
SHENANDOAH
BAKER
JOHNSTON
BRECKENRIDGE AVE
GLENGARY
TURNPIKE
K-MART
CRESCENT
FOREST
CENTRE
MOORMAN
ESSEX
MELROSE
ORANGE
HANOVER
STAUNTON
MERCER
CARROLL
PENNSYLVANIA
DELAWARE
MASSACHUSETTS AV.
ANDREWS
LAKEVIEW DR
SPRINGHILL DR
FAIRLAND RD
MEADOWVIEW
BROOKLYN DR.
KIRKLAND
WESTPORT
WESTVIEW
ROPER
PATTERSON
CHAPMAN
LOUDON
RAILROAD
DUVAL
C
C-1
29
21
3
23
13
6

24TH STREET STUDY AREA

PLATE 4

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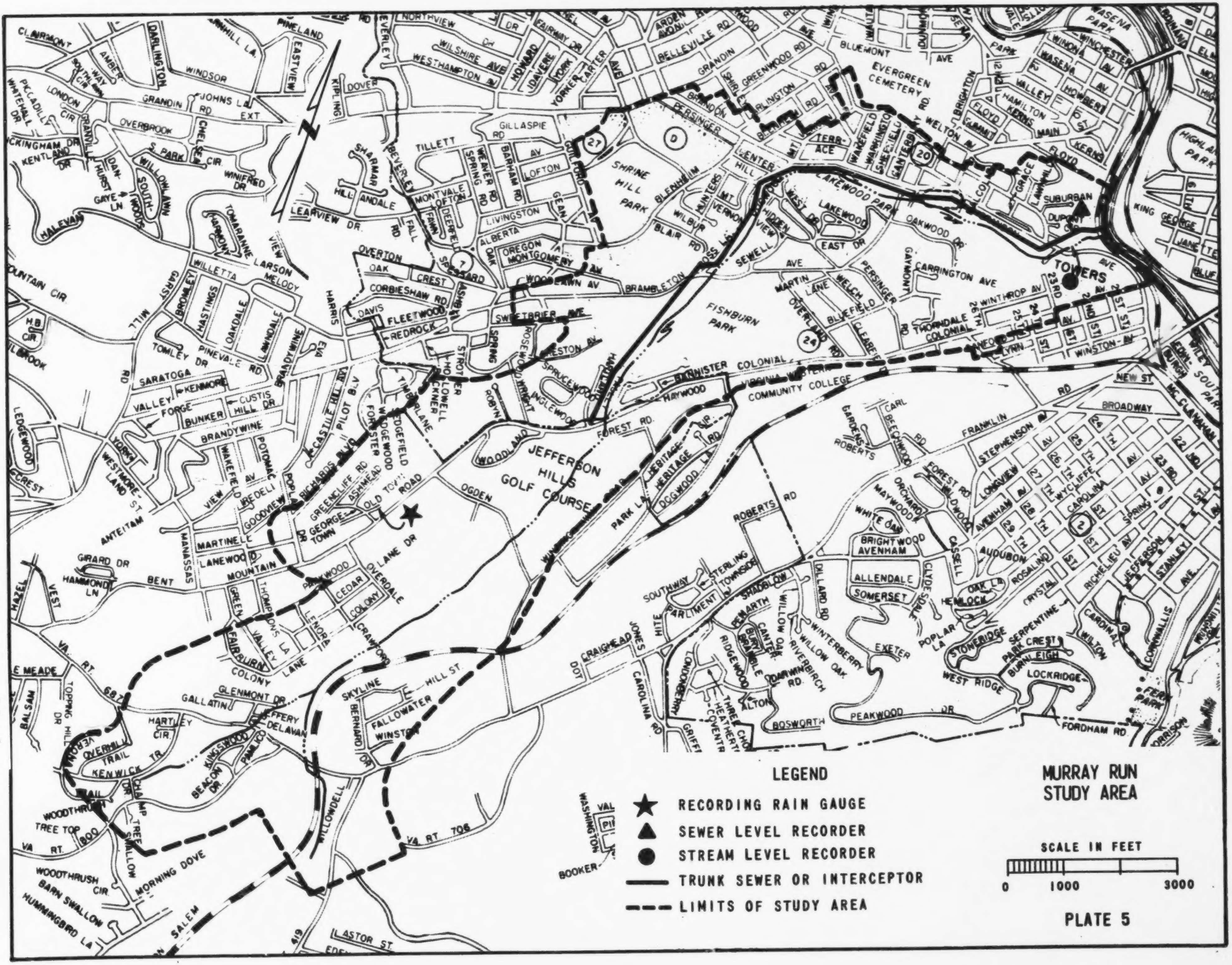

MURRAY RUN STUDY AREA

PLATE 5

LEGEND
★ RECORDING RAIN GAUGE
▲ SEWER LEVEL RECORDER
● STREAM LEVEL RECORDER
— TRUNK SEWER OR INTERCEPTOR
– – – LIMITS OF STUDY AREA
SCALE IN FEET
0
1000
3000
EVERGREEN CEMETERY
SHRINE HILL PARK
FISHBURN PARK
TOWERS
JEFFERSON HILLS GOLF COURSE
COMMUNITY COLLEGE
27
20
24
7
2

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TABLE 2

RAINFALL SUMMARY

Rainfall Event	Murray Run			Trout Run			24th Street			Woodrum Field		
	Average Intensity (in./hr.)	Duration (hrs.)	Total Rainfall (inches)	Average Intensity (in./hr.)	Duration (hrs.)	Total Rainfall (inches)	Average Intensity (in./hr.)	Duration (hrs.)	Total Rainfall (inches)	Average Intensity (in./hr.)	Duration (hrs.)	Total Rainfall (inches)
6 Feb	0.053	4.5	0.24	0.053	4.5	0.24	0.053	4.5	0.24	0.034	7.0	0.24
8 Feb	0.057	2.8	0.16	0.057	2.8	0.16	0.057	2.8	0.16	0.060	9.0	0.54
24 Mar	0.074	14.0	1.03	0.074	14.0	1.03	0.074	14.0	1.03	0.064	14.0	0.89
24 Mar	0.087	4.8	0.42	0.088	4.8	0.42	0.088	4.8	0.42	0.061	7.0	0.43
18, 19 May	0.071	9.8	0.70	0.071	9.8	0.70	0.071	9.8	0.70	0.051	14.0	0.71
8, 9 June	0.000	0.0	0.00	0.203	3.0	0.61	0.203	3.0	0.61	0.200	3.0	0.60
9 June	1.000	0.1	0.10	0.413	0.8	0.33	0.413	0.8	0.33	0.165	2.0	0.33
14 June	0.409	2.3	0.94	0.000	0.0	0.00	0.000	0.0	0.00	0.000	0.0	0.00
15 June	0.126	5.8	0.73	0.076	6.6	0.50	0.076	6.6	0.50	0.071	7.0	0.50
21 June	0.209	2.2	0.46	0.628	3.6	2.26	0.628	3.6	2.26	0.565	4.0	2.26
1, 2 July	0.000	0.0	0.00	0.307	1.3	0.40	0.231	1.3	0.30	0.440	2.0	0.88
2 July	0.000	0.0	0.00	0.253	1.3	0.33	0.231	1.3	0.30	0.140	1.0	0.14
12 July	0.243	0.7	0.17	0.514	0.7	0.36	0.514	0.7	0.36	0.180	2.0	0.36
19 July	0.563	0.8	0.45	0.625	0.8	0.50	0.625	0.8	0.50	0.000	0.0	0.00
22, 23 July	0.391	1.1	0.43	*	*	0.79	*	*	0.70	0.100	2.0	0.20
3 Aug	0.175	2.0	0.35	0.015	4.5	0.70	0.015	4.5	0.70	0.122	6.0	0.73
5 Aug	0.263	1.9	0.50	0.289	1.9	0.55	0.289	1.9	0.55	0.000	0.0	0.00

*Duration and intensity unknown

Non-recording rain gauges were used in Trout Run and 24th Street study areas.
The Woodrum Field data are from official U. S. Weather Bureau records.
Intensity is computed average for the recorded rainfall period.

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24TH STREET STUDY AREA

The gauging station for the 24th Street stream consisted of a sharp-crested weir and a water level recorder. The station is shown in Figure 10, and the stage-discharge curve used to convert the depth recordings to stream flows is given in Figure 97 in Appendix VI.

A water level recorder was installed above a manhole to gauge the depth of flow in the 24th Street sanitary sewer interceptor. The installation is shown in Figure 11, and the stage-discharge curve for the sewer is given in Figure 100 in Appendix VI.

STORM SURFACE RUNOFF

Flows were gauged in one or more of the three streams during 15 separate rainfall events. Stream hydrographs were plotted for each recorded flow and are included in Figures 34 through 55 in Appendix VI. A sample hydrograph and rainfall intensity curve for Murray Run is shown on Figure 12. Surface runoff was calculated from these hydrographs for each rainfall event for which stream flow recordings were obtained. Table 3 shows storm surface runoff in terms of inches over the entire drainage area and in terms of gallons per acre. The ratio of total runoff to total rainfall for all monitored rainfall events are as follows:

- Murray Run - 0.10
- Trout Run - 0.16
- 24th Street - 0.12

Figures 13, 14 and 15 depict, graphically, the relationship between rainfall and surface runoff as measured in the three study areas during the study period.

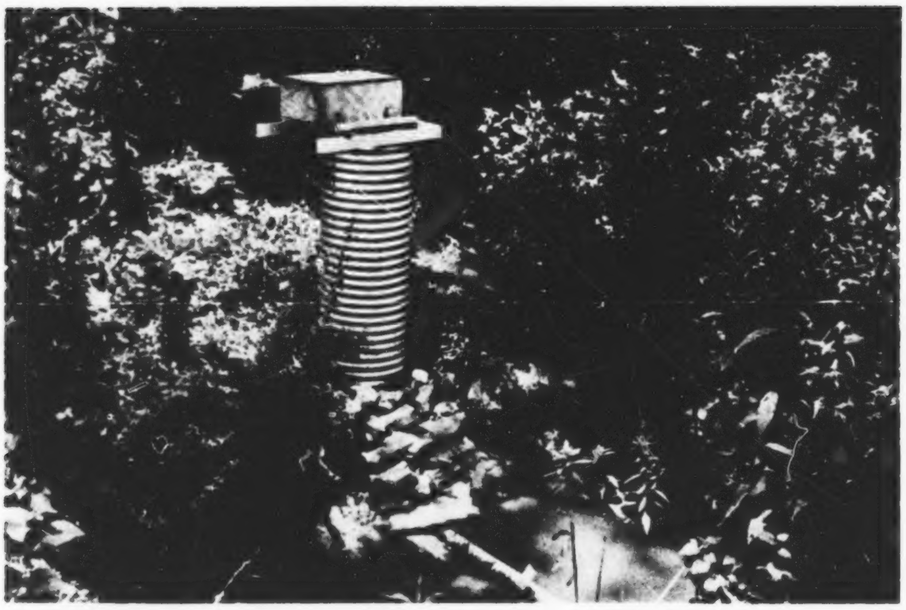


Figure 6. Water Level Recorder - Murray Run Stream

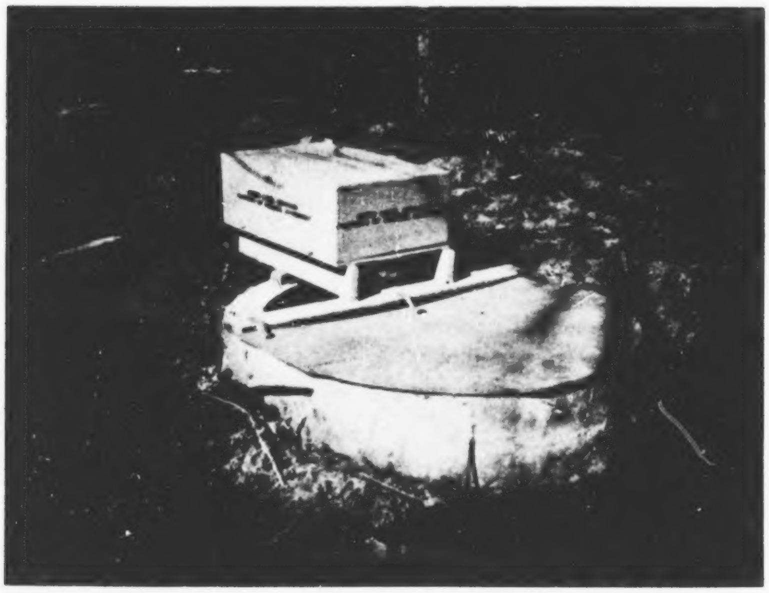


Figure 7. Water Level Recorder - Murray Run Sanitary Sewer

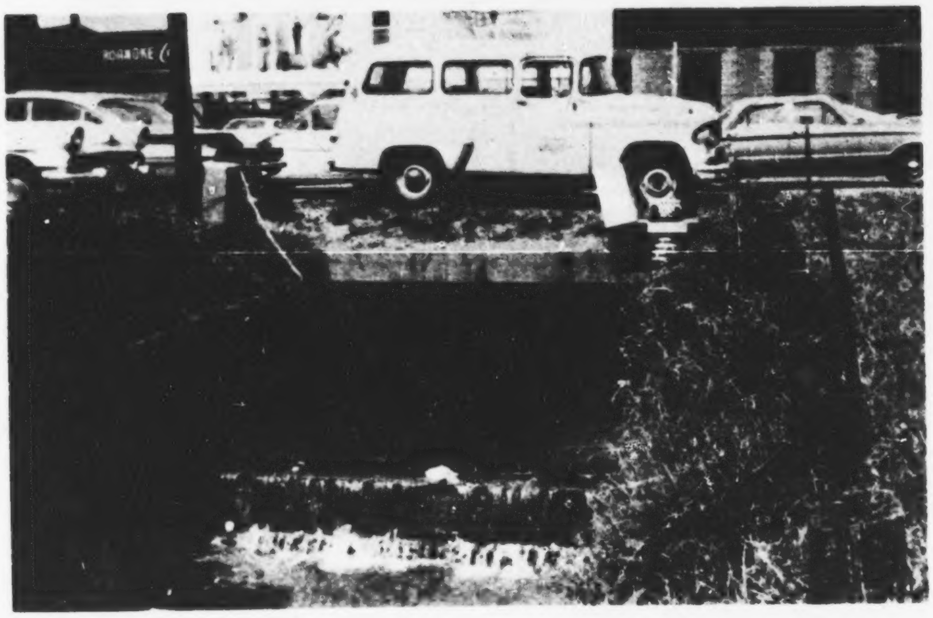


Figure 8. Water Level Recorder and Automatic Sampler - Trout Run Stream

Figure 9. Water Level Recorder and Automatic Sampler - Trout Run Sanitary Sewer

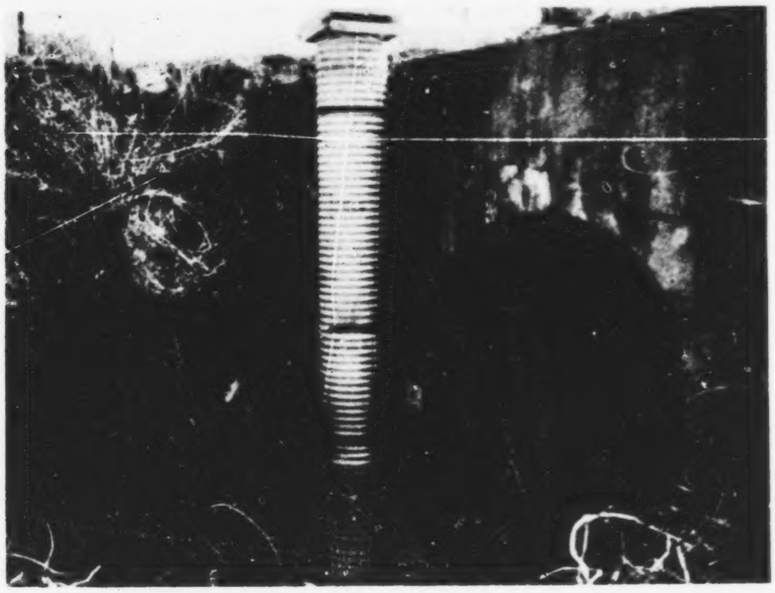


Figure 10. Water Level Recorder - 24th Street Stream

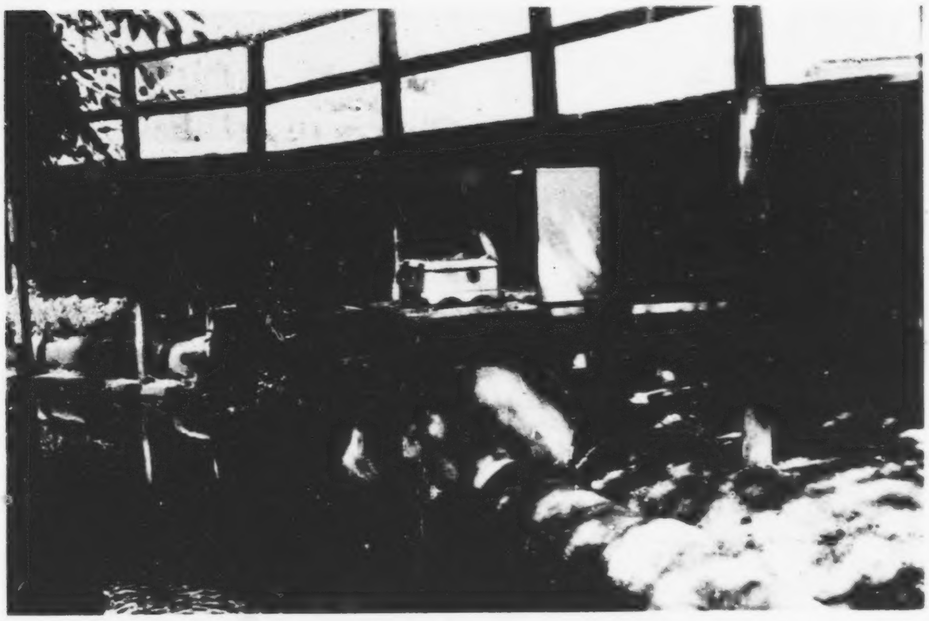


Figure 11. Water Level Recorder - 24th Street Sanitary Sewer

FIGURE 12 SAMPLE HYDROGRAPH
RAINFALL INTENSITY AND RATE OF DISCHARGE
MURRAY RUN STREAM

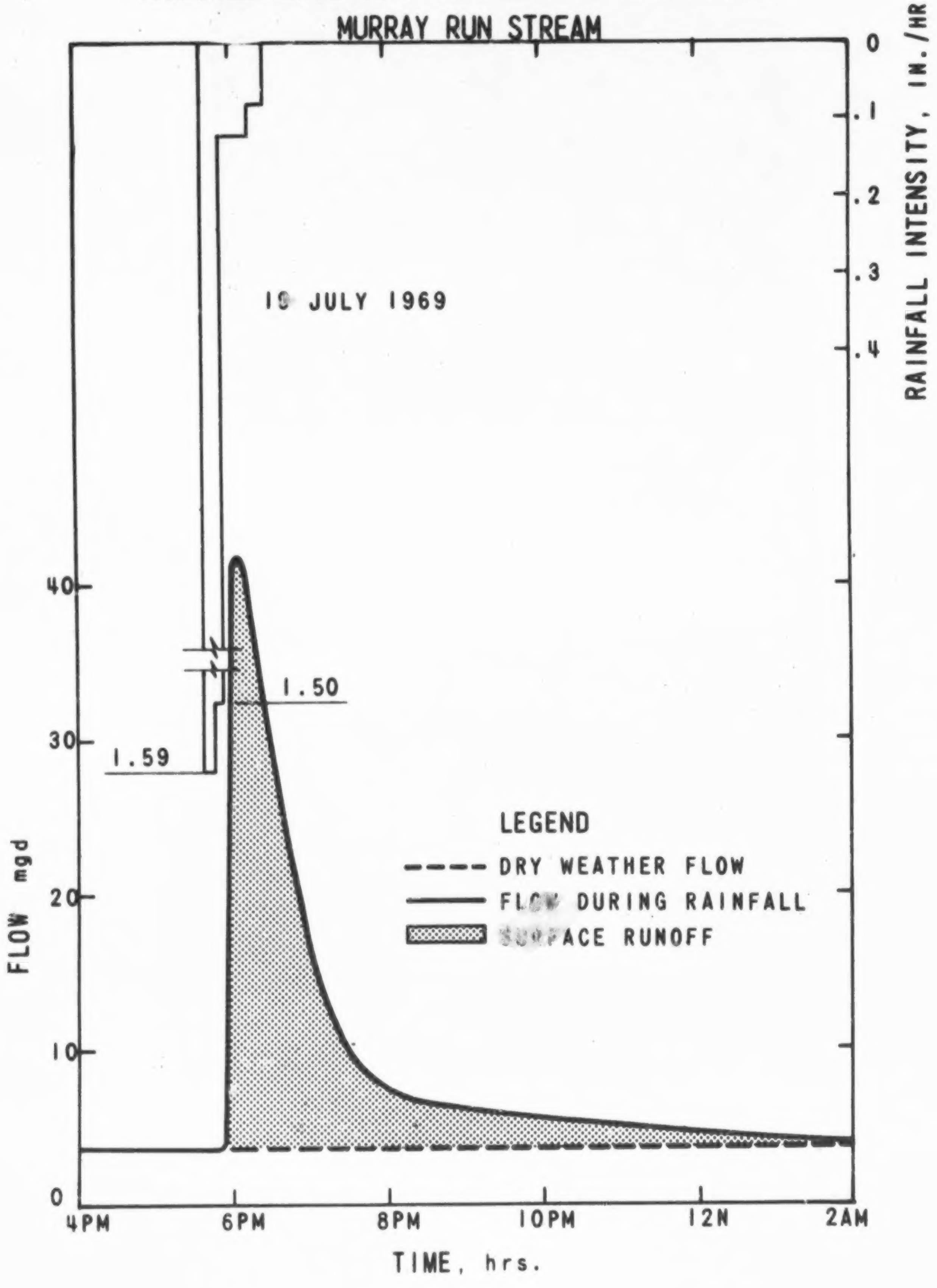


TABLE 3

STORM SURFACE RUNOFF

Rainfall Event	Murray Run Rainfall (inches)	Murray Run Runoff (inches)	Murray Run Runoff (gal./ac.)	Trout Run Rainfall (inches)	Trout Run Runoff (inches)	Trout Run Runoff (gal./ac.)	24th Street Rainfall (inches)	24th Street Runoff (inches)	24th Street Runoff (gal./ac.)
6 Feb	0.24	0.020	533	0.24	0.021	582	0.24	0.009	242
8 Feb	0.16	0.012	336	0.16	0.026	712	0.16	0.022	590
24 Mar	1.03			1.03			1.03		
24, 25 Mar	0.42	0.165	4483	0.42	0.343	9303	0.42	0.189	5135
18, 19 May	0.70	*	*	0.70	0.102	2758	0.70	*	*
8, 9 June	0.00	*	*	0.61	0.067	1836	0.61	*	*
9 June	0.10	*	*	0.33	0.038	1043	0.33	*	*
15 June	0.73	*	*	0.50	0.116	3159	0.50	*	*
21 June	0.46	*	*	2.26	0.374	10,150	2.26	*	*
1, 2 July	0.00	*	*	0.40	0.085	2317	0.30	*	*
2 July	0.00	*	*	0.33	0.068	1836	0.30	*	*
12 July	0.17	*	*	0.36	0.039	1063	0.36	*	*
19 July	0.45	0.037	1007	0.50	0.080	2207	0.50	*	*
22, 23 July	0.43	*	*	0.79	0.048	1334	0.70	*	*
3 Aug	0.35	*	*	0.70	0.104	2831	0.70	*	*

*Stream flow not recorded

FIGURE 13 RELATIONSHIP OF SURFACE RUNOFF TO RAINFALL
MURRAY RUN STREAM

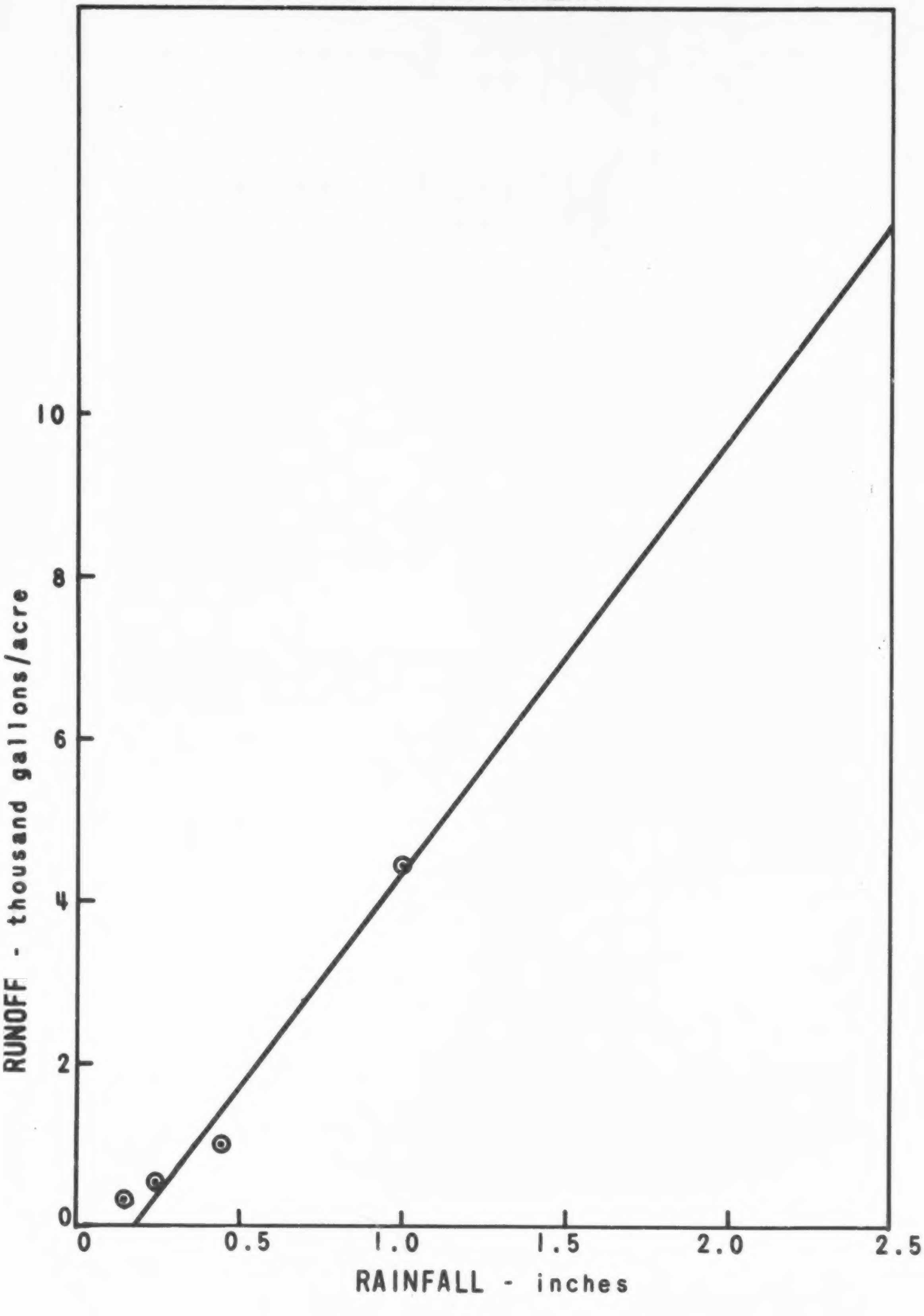


FIGURE 14 RELATIONSHIP OF SURFACE RUNOFF TO RAINFALL
24th STREET STREAM

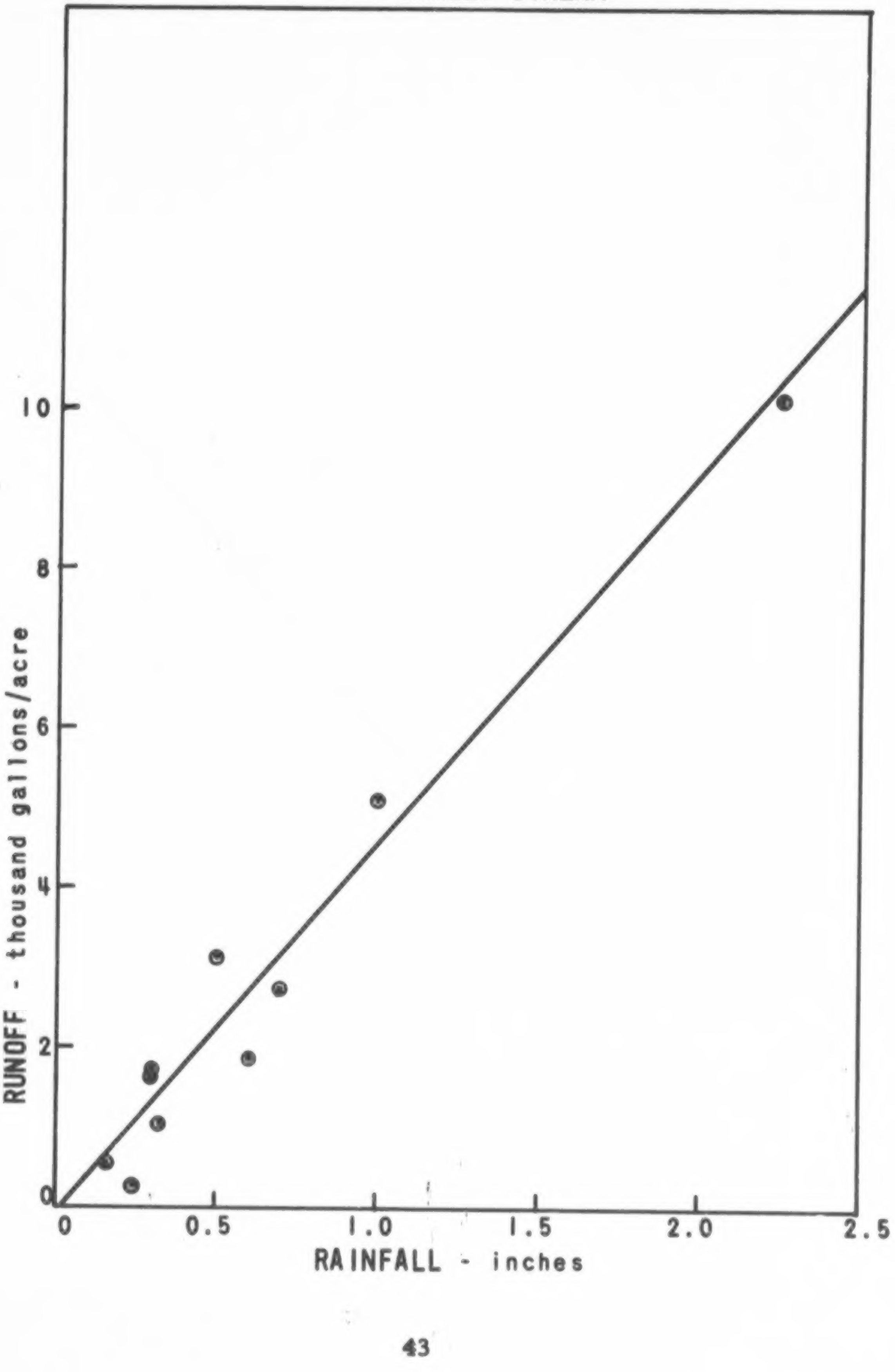
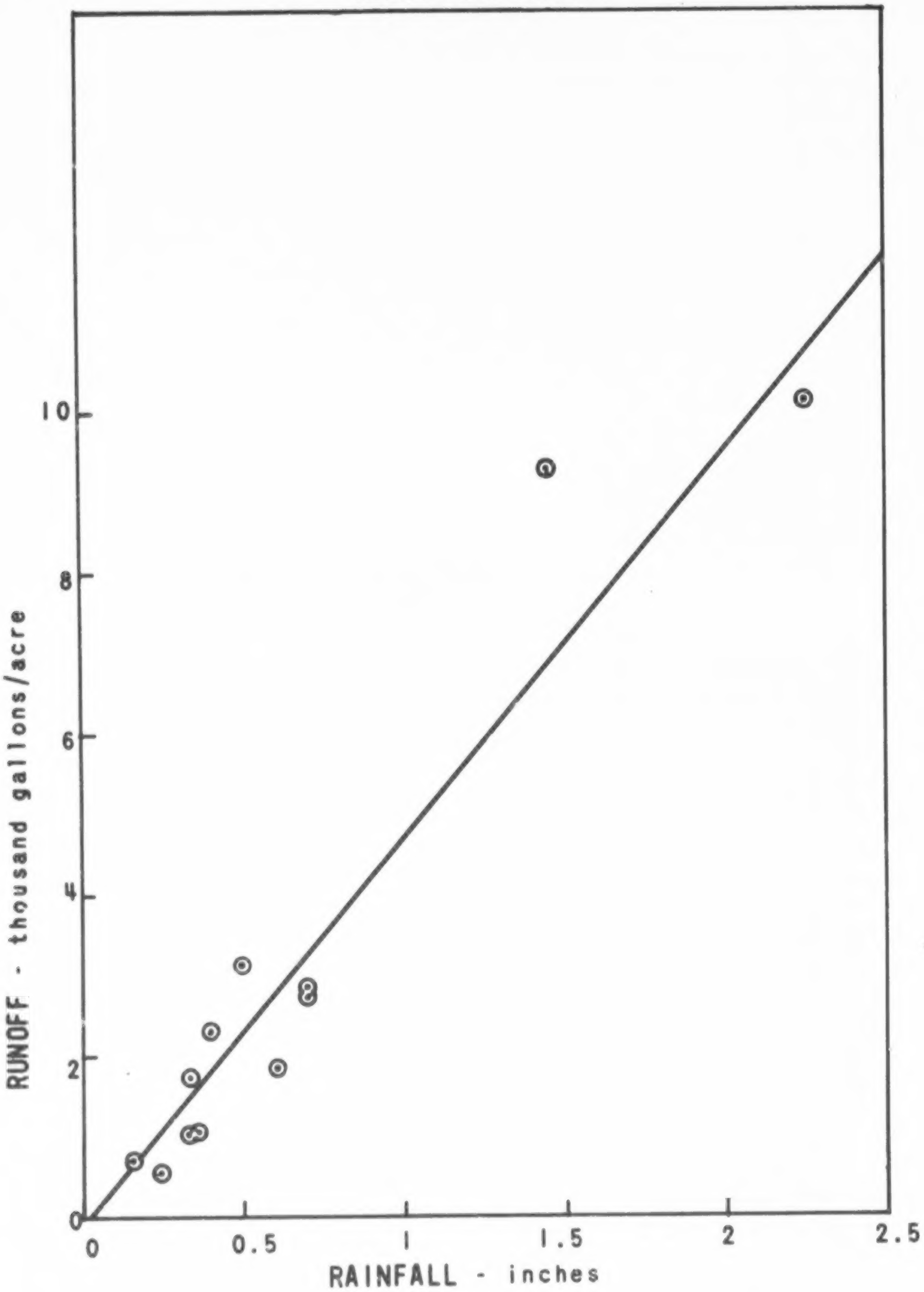


FIGURE 15 RELATIONSHIP OF SURFACE RUNOFF TO RAINFALL
TROUT RUN STREAM



STORM WATER INFILTRATION

Depths of flow were gauged in one or more sanitary sewer interceptors during sixteen rainfall events. The results of the gauging were used to plot sewer hydrographs, such as the one shown on Figure 16. The hydrographs are included as Figures 56 through 88 in Appendix VI.

The area of the shaded portion of the hydrograph represents storm water infiltration. The volume of storm water infiltration in the sewers was determined using the hydrographs and is summarized in Table 4. The hydrographs indicate that the Murray Run and Trout Run interceptors were surcharged during many of the storms. Flows under surcharge conditions were not measured; therefore, the amounts of infiltration were not measured during these events and volumes are not listed in Table 4.

Overflows that did occur were generally spread out over the entire interceptor line. Except in a few isolated instances, there were no intentional overflow pipes installed to discharge the overflow directly to a stream.

Initially, it was assumed that the dry weather flows in the sanitary sewer interceptors would remain relatively constant from day to day and no attempt was made to continually gauge the sewers during dry weather. During the course of the study, however, it was found that there was a significant change in the daily dry weather flow in the interceptors.

Figure 17 shows dry weather flows in the 24th Street interceptor recorded on 15 and 16 July and 29 and 30 April 1969. The flows are comparable in the respect that both represent a period beginning 12 noon on Tuesday and ending 12 noon on Wednesday. The shaded portion of the graph denotes the amount of variation in dry weather flow during the selected periods. It was observed that dry weather flow is dependent upon the rainfall conditions during the period preceding its recording. This can be illustrated by the fact that 4.8 inches of rainfall were recorded during the 30-day period preceding the date of the higher flow shown by Figure 17, while only 1.4 inches were recorded during a similar period preceding the date of the lower flow. A plausible explanation for the variation in the dry weather flow seems to be that the amount of ground water infiltration varies according to the antecedent rainfalls.

FIGURE 16 SAMPLE HYDROGRAPH
RAINFALL INTENSITY AND RATE OF DISCHARGE
24th STREET SANITARY SEWER

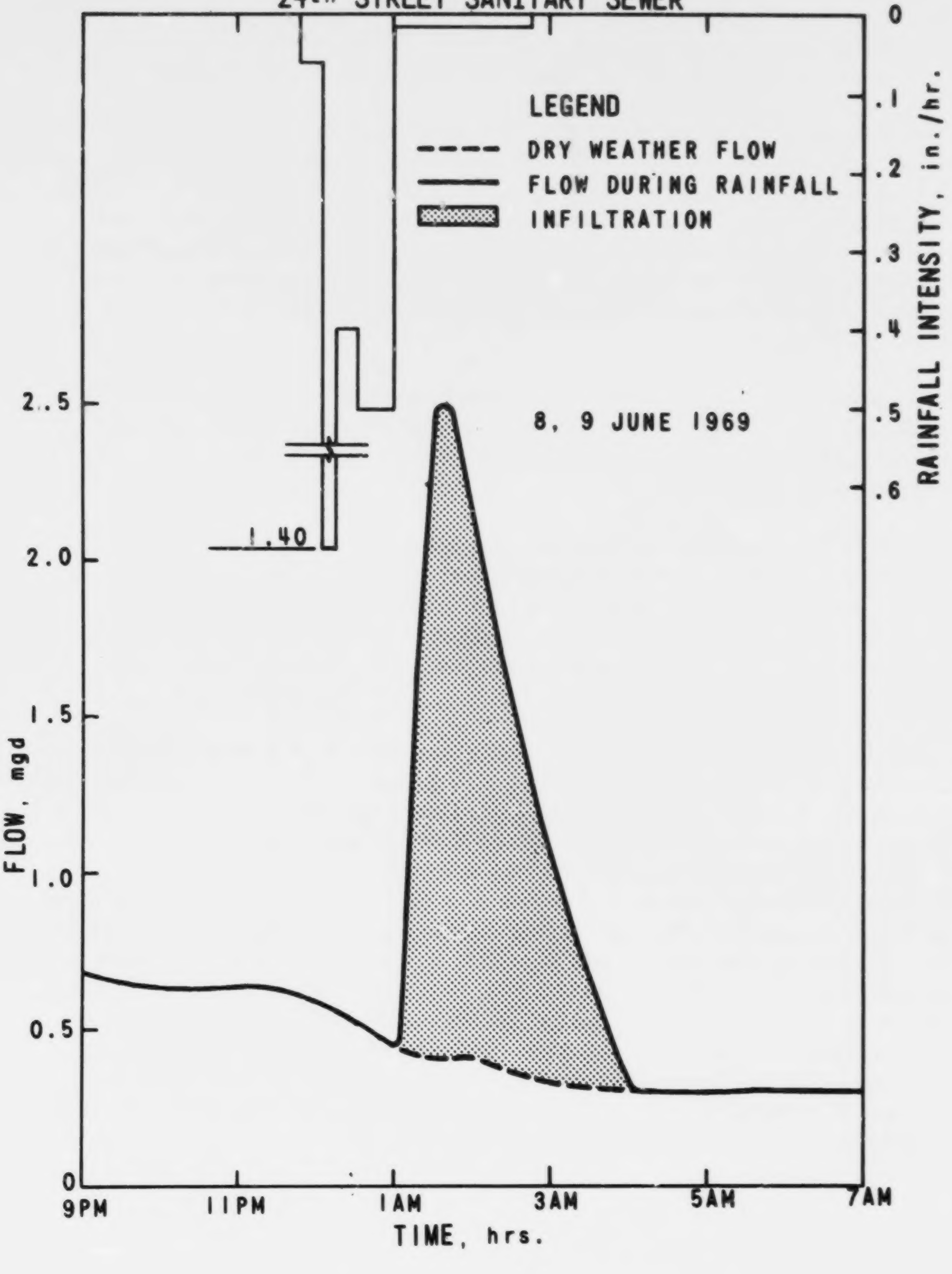


TABLE 4

STORM WATER INFILTRATION IN SANITARY SEWERS

Rainfall Event	Murray Run Sewer		Trout Run Sewer		24th Street Sewer	
	Rainfall (inches)	Infiltration (gallons)	Rainfall (inches)	Infiltration (gallons)	Rainfall (inches)	Infiltration (gallons)
6 Feb	0.24	*	0.24	No Data	0.24	31,200
8 Feb	0.16	*	0.16	No Data	0.16	35,400
24 Mar	1.03	*	1.03	No Data	1.03	256,000
24, 25 Mar	0.42	*	0.42	No Data	0.42	No Data
18, 19 May	0.70	*	0.70	62,500	0.70	293,000
8, 9 June	0.00	0	0.61	12,510	0.61	126,000
9 June	0.10	46,704	0.33	18,760	0.33	46,700
14 June	0.94	*	0.00	0	0.00	0
15 June	0.73	*	0.50	*	0.50	41,700
21 June	0.46	*	2.26	*	2.26	62,500
1, 2 July	0.00	0	0.40	*	0.30	182,000
2 July	0.00	0	0.33	*	0.30	192,000
12 July	0.17	*	0.36	*	0.36	84,200
19 July	0.45	*	0.50	*	0.50	No Data
22, 23 July	0.43	*	0.79	*	0.70	No Data
3 Aug	0.35	*	0.73	*	0.73	No Data

*Sewer surcharged

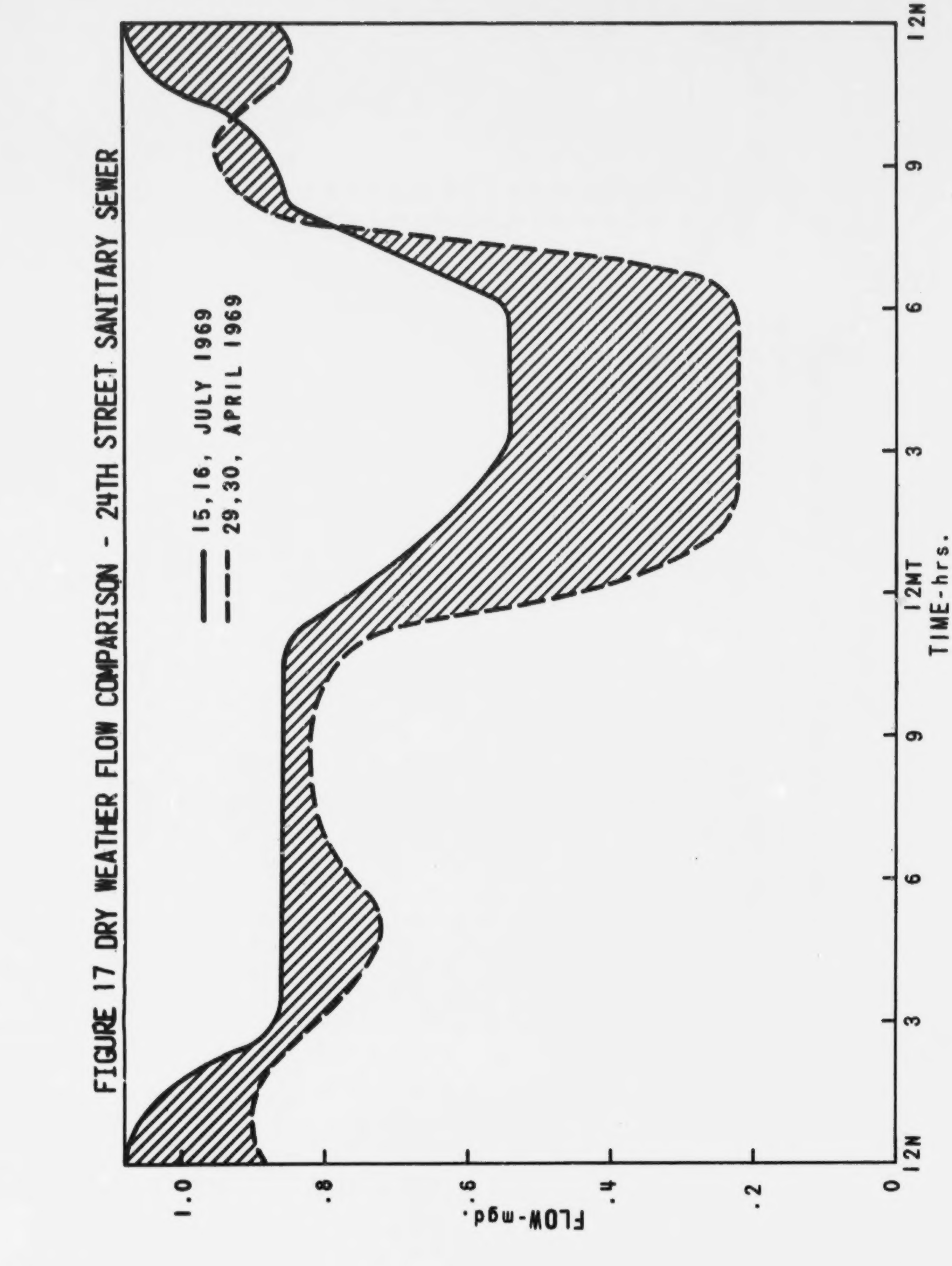


FIGURE 17 DRY WEATHER FLOW COMPARISON - 24TH STREET SANITARY SEWER

From the time that this variation was discovered, dry weather flows were monitored constantly in the interceptor sewers. This provided a reasonably accurate means of determining the portion of the total flow during rainfall that could be attributed entirely to storm water infiltration. The dry weather flows shown on Figures 56 through 88 in Appendix VI are flows recorded on days immediately preceding the rainfall event so that the shaded areas represent as nearly as possible the actual amount of storm water infiltration and include no ground water infiltration.

WATER QUALITY

Stream and sewage samples were taken in each of the three study areas and analyzed to determine the characteristics of the flow during rainfall and during dry weather. The samples were taken as nearly as possible to the location of the gauging installations, shown on Plates 3 through 5, to facilitate correlation of sampling characteristics and flow measurements.

Samples were taken systematically during rainfall and identified by a number, date, time, and place. The samples were obtained both manually and by automatic samplers. Samples were taken during three rainfalls in the Murray Run and 24th Street study areas and during five rainfalls in the Trout Run study area. The samples were tested for BOD, total solids, total volatile solids, suspended solids, suspended solids volatile, settleable solids and total coliform. The results of the stream and sewage sampling in the study areas are given in Tables 51 through 56 in Appendix VI.

Twenty four hour composite samples were taken and tested to determine the dry weather stream and sewage characteristics. These results are given in Tables 59 and 60 in Appendix VI.

The sampling results were correlated with flow measurements and used to compute the total pounds of pollutants reaching the streams from surface runoff and from sanitary sewage overflows. This information is given in Tables 5 through 7. The 24th Street sanitary sewer interceptor did not surcharge; therefore, it is assumed that the increase in pollutants in the stream over that normally present during dry weather is entirely the result of surface runoff.

TABLE 5

STREAM POLLUTION FROM SURFACE RUNOFF AND SANITARY SEWER OVERFLOWS

TROUT RUN

Date of Event	Rainfall (in.)	BOD (lbs.)	Total Solids (lbs.)	Volatile Solids (lbs.)	Suspended Solids (lbs.)	Volatile Suspended Solids (lbs.)
6 Feb 1969	0.24	73	1441	900	620	103
8 Feb 1969	0.16	83	4035	1128	1027	262
24 Mar 1969	1.00	410	15,284	5773	3296	1411
22/23 July 1969	0.79	316	16,358	3510	2103	472
3 August 1969	0.70	280	15,068	4509	1836	526

TABLE 6

STREAM POLLUTION FROM SURFACE RUNOFF*

24TH STREET

Date	Rainfall (in.)	BOD (lbs.)	Total Solids (lbs.)	Volatile Solids (lbs.)	Suspended Solids (lbs.)	Volatile Suspended Solids (lbs.)
6 Feb 1969	0.24	37	895	145	235	38
8 Feb 1969	0.16	202	3393	1330	603	285
24 Mar 1969	1.00	148	8361	2502	1250	353

*The interceptor did not surcharge during the sampling period; the results reflect pollution from storm surface runoff only.

TABLE 7

STREAM POLLUTION FROM SURFACE RUNOFF AND SANITARY SEWER OVERFLOWS

MURRAY RUN

Date	Rainfall (in.)	BOD (lbs.)	Total Solids (lbs.)	Volatile Solids (lbs.)	Suspended Solids (lbs.)	Volatile Suspended Solids (lbs.)
6 Feb 1969	0.24	200	7982	2154	1644	722
8 Feb 1969	0.16	0	966	409	0	0
24 Mar 1969	1.00	329	12,552	3122	318	155

WATER POLLUTION CONTROL PLANT

GAUGING

The gauging technique used at the Water Pollution Control Plant was similar to that employed in the study areas, except the gauging at the plant was used to monitor the flow in the overflow pipe located in the wet well intake structure just outside the main building. A more detailed description of the method of gauging is given in Appendix III.

Figure 18. Water Level Recorder - Water Pollution Control Plant

Table 8 summarizes the data from the gauging of the overflow at the Water Pollution Control Plant.

Reference should be made to Appendix VI, Figures 89 through 94 and Figure 101, for graphs showing discharge of the overflow versus time and a stage discharge curve for the plant overflow pipe.

TABLE 8

OVERFLOWS AT THE WATER POLLUTION CONTROL PLANT

Date of Event	Total Rainfall (in.)	Duration (hrs.)	Average Intensity (in./hr.)	Total Overflow (mg)
24 Mar 1969	1.00	10.0*	0.10	2.8
21 Jun 1969	1.25	3.5	0.36	2.9
19 Jul 1969	0.50	0.8	0.63	0.6
22, 23 Jul 1969	0.60	1.6	0.37	0.7
3 Aug 1969	0.50	4.5	0.11	.04
5 Aug 1969	0.50	1.9	0.26	.02

*Duration reduced to 10 hours because the event exceeded overflow at the plant.

OVERFLOW QUALITY

Samples of the plant influent were obtained manually by taking grab samples in the comminutor room. Automatic samplers were initially installed but were ineffective because of blockage in the nozzle openings due to solids. A more detailed description of the sampling technique is given in Appendix IV.

Table 9 shows the results of sampling during overflow caused by the rainfall on 23 July 1969. Complete analysis of the sampling is given in Tables 57 and 58, in Appendix VI.

TABLE 9

CONTRIBUTION FROM TYPICAL OVERFLOW FROM WATER POLLUTION CONTROL PLANT

22/23 JULY 1969 EVENT

Rainfall (in.)	Total Overflow (mg)	BOD (lbs.)	Total Solids (lbs.)	Total Volatile Solids (lbs.)	Suspended Solids (lbs.)	Suspended Solids Volatile (lbs.)
0.60	0.7	1192	4892	2672	648	312

Tables 10 and 11 show average waste water characteristics at the plant overflow and sampling characteristics at an upstream manhole in the Roanoke River Interceptor during the 22/23 July 1969 event. This data indicates that the concentrations of pollutants in the overflow at the plant are about twice that of the incoming sewage just upstream from the plant. A check of the plant piping arrangement revealed that digester supernatant and sludge thickner effluent were returned to the overflow manhole and mixed with incoming raw sewage, thus increasing the concentration of the mixture. During overflows this more concentrated mixture is flushed into the Roanoke River.

TABLE 10

WASTE WATER OVERFLOW CHARACTERISTICS

WATER POLLUTION CONTROL PLANT

22/23 JULY 1969 EVENT

Total Over-flow Rate (mgd)	BOD (mg./1.)	Total Solids (mg./1.)	Total Volatile Solids (mg./1.)	Suspended Solids (mg./1.)	Suspended Solids Volatile (mg./1.)	Setteable Solids (ml./1.)	Coliform MPN per 100 ml (thousands)
6.5	239	567	513	126	64	21	51,000

TABLE 11

PLANT WASTE WATER INFLUENT CHARACTERISTICS

UPSTREAM MANHOLE RCANOKE RIVER INTERCEPTOR

22/23 JULY 1969 EVENT

Flow (mgd)	BOD (mg./1.)	Total Solids (mg./1.)	Total Volatile Solids (mg./1.)	Suspended Solids (mg./1.)	Suspended Solids Volatile (mg./1.)	Setteable Solids (mg./1.)	Coliform MPN per 100 ml (thousands)
Not available	115	683	337	78	38	6	73,000

SECTION 5

EVALUATION OF RESULTS

FIELD INVESTIGATION

One of the objectives of this study was to establish a relationship between the topographic, physical, and socio-economic characteristics of the study areas and the quantities of storm water infiltration measured in the sanitary sewer interceptors. This was to be accomplished by comparing the relative quantities of storm water infiltration in the three study areas with the differing characteristics of the three areas. The lack of a suitable method of measuring surcharge flows and overflows in the sanitary sewer interceptors handicapped efforts to make such a comparison. Both the Murray Run and Trout Run interceptors became surcharged under very low intensity rainfall conditions, and infiltration was not measured in these sewers for the vast majority of the rainfall events during the study period. Only during three rainfall events was it possible to gauge flows in two or more of the three interceptors. Table 12 gives the amount of storm water infiltration and the ratio of infiltration to rainfall for these three events. When the infiltration values are compared with the various study area characteristics, given in Table 13, no logical relationship between infiltration and the study area characteristics is apparent.

Although these results show no logical relationship between study area characteristics and storm water infiltration, the findings are by no means conclusive. In fact, it is entirely possible that the method of measuring storm water infiltration in the Trout Run and Murray Run sewers was not sufficiently accurate to establish such a relationship.

As explained in Section 4 - Results of Investigation, the total storm water infiltration in a study area for a particular rainfall was derived from the shaded portion of the hydrograph of the sewer. An example hydrograph is given in Figure 16. This is an accurate measure of infiltration if the sewer does not surcharge and/or overflow upstream from the gauging installation. When overflow does occur upstream, however, the amount of infiltration measured at the gauging installation is less than the actual amount of infiltration.

An upstream overflow is likely to occur when the capacity of the sewer line immediately upstream from the gauge is significantly less than the line capacity at the gauge. This condition of a reduced line capacity immediately upstream from the gauge exists in both the Murray Run and

TABLE 12

COMPARISON OF INFILTRATION TO RAINFALL IN THE THREE STUDY AREAS

	Murray Run			Trout Run			24th Street		
Rainfall Event	Infil. (gal.)	Rainfall (in.)	Infil./ Rainfall (gal./in.)	Infil. (gal.)	Rainfall (in.)	Infil./ Rainfall (gal./in.)	Infil. (gal.)	Rainfall (in.)	Infil./ Rainfall (gal./in.)
18, 19 May	*	0.70	-	62,500	0.70	89,000	293,000	0.70	419,000
8, 9 June	0	0	-	12,510	0.61	20,100	126,000	0.61	206,000
9 June	46,700	0.10	467,000	18,760	0.33	57,000	46,700	0.33	142,000

*Sewer surcharged

TABLE 13

STUDY AREA CHARACTERISTICS

Drainage Area	Area (acres)	Estimated Average Age Of Buildings (years)	Length of Sewer Line (ft.)	Length of Paved Street (ft.)	Develop. Density (buildings/acre)	Number Of Storm Water Entry Points	Popu-lation	Estimated Average Value Of Dwellings
Murray Run	909	15	95,000	97,000	1	149	6,000	$35,000
Trout Run	997	35	60,000	172,200	3	273	11,000	$ 5,000
24th Street	1034	25	93,000	104,600	1	87	10,000	$15,000

Trout Run study areas; gauges were located to monitor the entire study area and to permit monitoring of low-intensity rainfall events. Although no upstream overflows were actually observed in these areas during the rainfall events listed in Table 12, unobserved overflows are a distinct possibility. In the 24th Street interceptor, the gauge is located such that the line capacity upstream was greater than at the gauge for a distance of approximately 3500 feet; thus, the possibility of an upstream overflow is extremely remote. The infiltration values listed in Table 4 and 12 for the 24th Street study area are, therefore, considered to be a true measure of the total amount of storm water infiltration from the entire study area.

STREAMS

DRY WEATHER CONDITIONS

The average dry weather flows in the streams in the three study areas are approximately as follows:

- Murray Run - 4.0 mgd
- Trout Run - 1.0 mgd
- 24th Street - 0.7 mgd

The average daily and annual pollutional loads in the streams, computed from the above flows and the dry weather sampling data in Table 60 in Appendix VI, are given in Table 14.

WET WEATHER CONDITIONS

The pollutional load in the streams is considerably increased during rainfalls as a result of surface runoff and sanitary sewer overflows. Table 15 gives a comparison of the relative concentrations of the pollutional constituents during average wet weather and average dry weather conditions. The wet weather concentrations are three to six times greater than dry weather concentrations for all constituents. Since the wet weather flows are also higher, the total pollutional load is much greater during rainfall.

In the 24th Street study area, the increase in pollutional load in the stream can be attributed entirely to surface runoff since there were no sanitary sewer overflows during the rainfall events sampled. Table 16

TABLE 14

DAILY AND ANNUAL DRY WEATHER POLLUTIONAL LOADS IN STREAMS

	Constituents (pounds)									
	BOD		Total Solids		Total Volatile Solids		Suspended Solids		Suspended Solids Volatile	
Stream	Daily	Annual (1000)	Daily	Annual (1000)	Daily	Annual (1000)	Daily	Annual (1000)	Daily	Annual (1000)
Murray Run	256	93	8278	3020	2837	1036	1235	451	401	146
Trout Run	25	9	2345	856	1227	448	142	52	67	25
24th Street	44	16	1133	414	736	269	117	43	41	15

TABLE 15

RELATIVE CONCENTRATIONS OF POLLUTIONAL CONSTITUENTS DURING AVERAGE WET WEATHER AND AVERAGE DRY WEATHER CONDITIONS

	BOD (mg./l.)		Total Solids (mg./l.)		Total Volatile Solids (mg./l.)		Suspended Solids (mg./l.)		Suspended Solids Volatile (mg./l.)		Settleable Solids (ml./l.)		Flow (mgd)	
Stream	Wet Weather	Dry Weather	Wet Weather	Dry Weather	Wet Weather	Dry Weather	Wet Weather	Dry Weather	Wet Weather	Dry Weather	Wet Weather	Dry Weather	Wet Weather	Dry Weather
Murray Run	17	8	623	248	134	85	89	37	25	12	2	0	7.7	4.0
Trout Run	18	3	460	281	139	147	93	17	28	8	3	0	13.8	1.0
24th Street	20	8	514	194	172	126	103	20	34	7	3	0	3.4	0.7

gives the concentrations of the pollutional constituents of the surface runoff in the 24th Street study area in comparison with concentrations measured in an urban study area in Cincinnati, Ohio.

The Cincinnati study was conducted during the period July 1962 through July 1964 on a 27-acre drainage area (4). The area was similar to the 24th Street study area in that it contained residential and light commercial development. However, the density of development in the Cincinnati area was greater than 3 buildings per acre compared with approximately 1 building per acre in the 24th Street study area, partially accounting for the higher values in Cincinnati.

TABLE 16

COMPARISON OF CONCENTRATIONS OF POLLUTIONAL CONSTITUENTS FROM SURFACE RUNOFF

	24th Street Study Area	Cincinnati Study Area
BOD (mg. /l.)	7	17
Total Solids (mg. /l.)	230	-
Total Volatile Solids (mg. /l.)	68	-
Suspended Solids (mg. /l.)	39	227
Suspended Solids Volatile (mg. /l.)	13	57

Unlike the 24th Street study area, the sanitary sewers surchared in the Trout Run and Murray Run areas during the rainfall events in which the streams were sampled. Sanitary sewage overflows were actually observed in the Murray Run area during the 24 March rainfall and in Trout Run during the 24 March, 22/23 July and 3 August events. No overflows were observed in either of these two areas during the 6 February and 8 February rainfall events. The sampling data from these two events, therefore, have been used to determine the characteristics of the surface runoff from these two areas. Table 17 gives the average concentrations of the pollutional constituents attributed to surface runoff from these two rainfalls. It is pointed out, however, that although no sanitary sewage overflows were observed, the sewer lines did surcharge and there is a possibility that sanitary sewage reached the stream from an unobserved overflow or by exfiltration from leaks in the line.

TABLE 17

AVERAGE CONCENTRATION OF POLLUTIONAL CONSTITUENTS IN STREAMS ATTRIBUTED TO SURFACE RUNOFF

	Murray Run Study Area	Trout Run Study Area
BOD (mg./l.)	26	15
Total Solids (mg./l.)	937	510
Total Volatile Solids (mg./l.)	212	189
Suspended Solids (mg./l.)	285	153
Suspended Solids Volatile (mg./l.)	83	34

Table 18 gives a comparison of the average pollutants from surface runoff in terms of pounds per acre per inch of rainfall. The values in Table 18, determined from sampling data on rainfall events when no overflows were observed, were used to determine pollution attributed entirely to surface runoff. The amounts of pollution from surface runoff thus determined and the amount of normal dry weather flow pollution were subtracted from the total pollution in the stream to determine the amount of pollution from the sanitary sewer overflows. Tables 19 and 20 give a breakdown of the pollutional load in the streams during the rainfall events sampled.

Table 20 shows that the pollutional load was increased considerably in the Trout Run stream during the 24 March, 22/23 July and 3 August rainfalls when the sanitary sewer was observed to have overflowed. Sewer overflows contributed more BOD to the stream during the 24 March and 3 August rainfalls than was contributed by surface runoff.

SANITARY SEWERS

INFILTRATION

A primary objective of this study was to determine the frequency and the magnitude of sanitary sewer overflows in the study areas and to develop remedial measures aimed at decreasing both the frequency and the magnitude of such overflows.

TABLE 18

COMPARISON OF AVERAGE POLLUTANTS FROM SURFACE RUNOFF

Study Area	BOD (lbs./ac./in.)	Total Solids (lbs./ac./in.)	Total Volatile Solids (lbs./ac./in.)	Suspended Solids (lbs./ac./in.)	Suspended Solids Volatile (lbs./ac./in.)
Trout Run	0.39	13.7	5.1	4.1	0.9
Murray Run	0.46	16.9	4.0	5.2	1.5
24th Street	0.25	8.2	2.3	1.4	0.5

TABLE 19

SUMMARY OF TOTAL POUNDS OF POLLUTANTS IN MURRAY RUN STREAM

Rainfall Event 1969	BOD (lbs.)			Total Solids (lbs.)			Volatile Solids (lbs.)			Suspended Solids (lbs.)			Volatile Suspended Solids (lbs.)		
	DWF*	Surface Runoff	Sewage Overflows	DWF*	Surface Runoff	Sewage Overflows	DWF*	Surface Runoff	Sewage Overflows	DWF*	Surface Runoff	Sewage Overflows	DWF*	Surface Runoff	Sewage Overflows
6 Feb	114	326	-	3650	10,273	-	1251	2304	-	545	3325	-	177	1002	-
8 Feb	53	11	-	1722	2046	-	590	480	-	257	429	-	83	91	-
24 Mar	167	538	-	5860	16,220	-	2009	3359	-	874	3014	-	284	604	-

*DWF = Dry Weather Flow

TABLE 20

SUMMARY OF TOTAL POUNDS OF POLLUTANTS IN TROUT RUN STREAM

Rainfall Event 1969	BCD (lbs.)			Total Solids (lbs.)			Volatile Solids (lbs.)			Suspended Solids (lbs.)			Volatile Suspended Solids (lbs.)		
	DWF*	Surface Run-off	Sewage Overflows	DWF*	Surface Run-off	Sewage Overflows	DWF*	Surface Run-off	Sewage Overflows	DWF*	Surface Run-off	Sewage Overflows	DWF*	Surface Run-off	Sewage Overflows
6 Feb	5	73	-	879	1441	-	460	900	-	52	620	-	25	103	-
8 Feb	4	83	-	489	4035	-	256	1128	-	29	1027	-	14	262	-
24 Mar	17	388	965	1612	13,659	1625	843	5773	-	96	3296	-	45	897	514
22/23 July	6	307	227	562	10,767	5559	294	3510	-	33	3190	1087	16	472	-
3 Aug	10	272	308	912	9571	5497	477	3589	920	54	1836	-	26	526	-

*DWF = Dry Weather Flow

It was not possible to actually gauge the quantity of the overflows because of their type and location. Overflows that did occur were generally spread out over the entire interceptor line. Except in a few isolated instances there were no intentional overflowpipes installed to discharge the overflow directly to a stream. When the pipeline capacity was exceeded, the excess flow exited by manholes, or small breaks in lines, backed up into basements, ponded in surface depressions, and infiltrated into the ground by other ways not visible.

Because of the types of overflows, a synthetic method of estimating overflow frequencies and magnitudes was developed. From the gauging data, a relationship was established between rainfall intensity and rate of infiltration into the sanitary sewers so that for any given rainfall intensity the rate of infiltration of surface water into the sanitary sewers could be estimated. When the total amount of infiltration for a given rainfall event was required the duration of the event was applied to the rainfall intensity. Through use of the derived relationship to estimate the infiltration, the total flow in the sewer during any given rainfall event can be estimated by adding the normal dry weather flow to the infiltration.

The total flow can then be compared with the capacity of the sewer to determine the amount of sewage overflow for a given rainfall event or the amount of flow that exited the system because the capacity was exceeded. A computer program was developed to expedite the tedious computations involved in calculating the sewage flows and overflows.

INFILTRATION - RAINFALL RELATIONSHIP

A relationship between rainfall intensity and the infiltration rate of storm water into the sanitary sewers was derived from data on the 24th Street study area given in Tables 2 and 4. The infiltration rate for a given rainfall event was taken to be the total quantity of storm water infiltration divided by the duration of the rainfall. To make the relationship applicable to other drainage areas and sub-drainage areas, the assumption was made that total infiltration was proportional to the length of collector and interceptor sewer lines in the area. Figure 19 shows graphically the relationship between rainfall intensity and infiltration rate in the 24th Street area. The equation of the line of best fit on the graph, as determined by stepwise multiple regression analysis, is as follows:

$$R = 1.984\, I - 0.087 \qquad \text{Equation 1}$$

R = Rate of surface water infiltration in mgd per 1000 linear feet of sewer line

I = Average rainfall intensity in inches per hour

The derived equation has a standard error of estimate of 0.017 and a multiple correlation coefficient of 0.995. These values indicate that the derived equation will predict, with a reasonable degree of accuracy, the amount of storm water infiltration in the 24th Street sewer for a given rainfall having an intensity in the range covered by the data points shown on Figure 19. The equation will probably be much less accurate, however, for higher intensity rainfalls during which sewer lines become surcharged. Once a sewer line surcharges, it is obvious that little or no more storm water will infiltrate into the line. This means that the infiltration rate for that particular line will approach zero. If many lines surcharge during a rainfall event, the infiltration rate computed by the equation would be significantly higher than that which actually occurred. No data were gathered in this study, however, to indicate at what point the rate of infiltration begins to decrease.

In the three study areas, the collector sewers account for between 88 and 92 percent of the total collector-interceptor system. The collector sewers are 8- and 10-inch lines and generally have the capacity to carry from 4 to 10 times the dry weather flow. With this amount of excess capacity, it would take a very high intensity rainfall to surcharge the collector lines. For example, it would take a 1-hour rainfall having an intensity of 1.2 inches per hour to surcharge an 8-inch line on minimum slope and 2000 feet in length. This intensity is greater than any recorded during the study period. Therefore, for the purposes of this study, the equation derived from Figure 19 was used to compute infiltration rates for all rainfall events in the three study areas.

COMPUTER PROGRAM

A computer program was developed to determine, for any given rainfall event, the locations and amounts of overflow in the interceptor for a particular drainage area. Four sets of input data are required for the program:

1. The slopes and diameters of the line sections between each pair of manholes.

2. The length of collectors and interceptors contributing to the flow in each line section.

3. The average dry weather flow from the entire drainage area.

4. The intensity and the duration of the rainfall event.

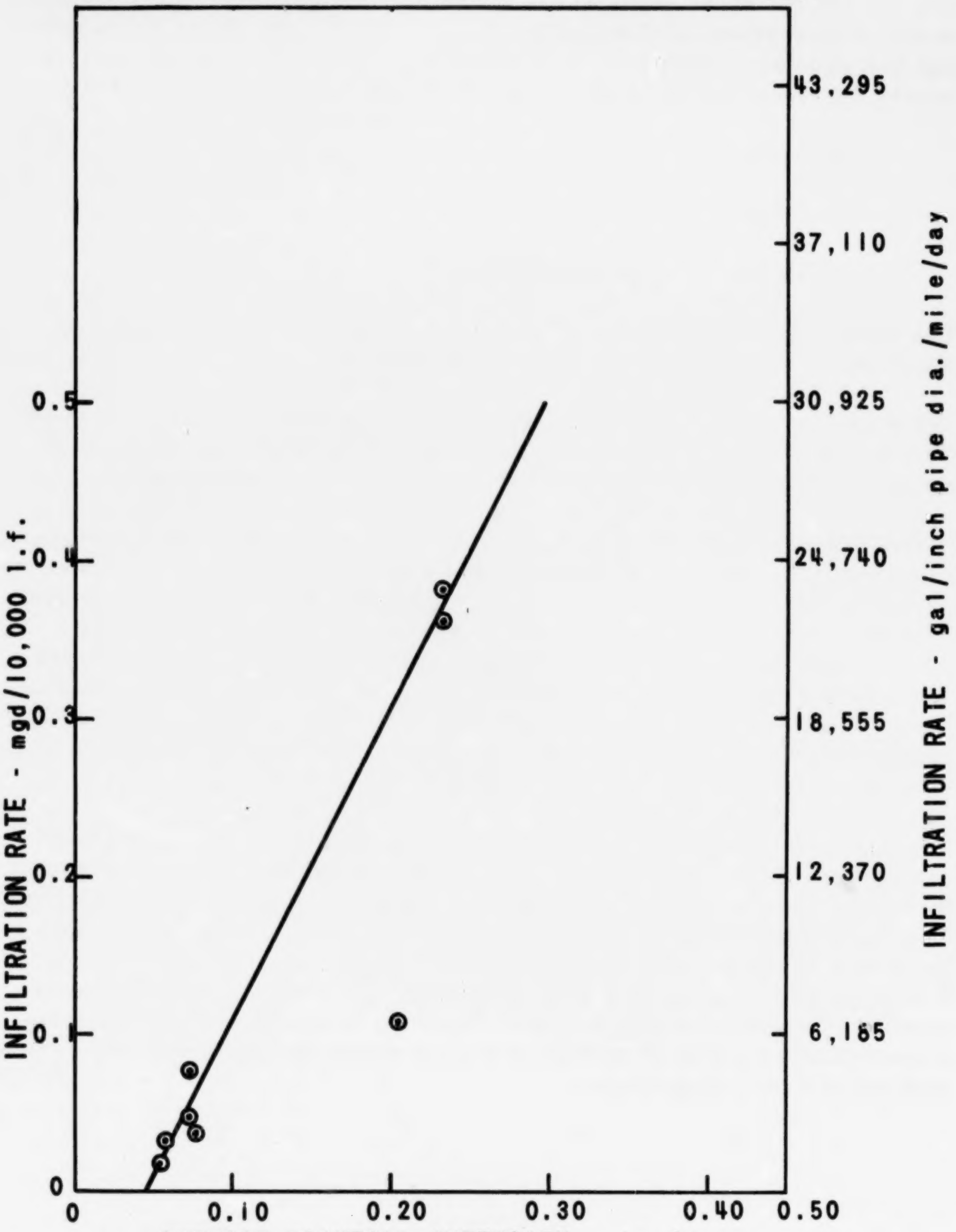
From the slopes and diameters, the program computes the capacity of each line section using the Manning Formula. The program computes the average dry weather flow in each line section by multiplying the average dry weather flow, from the entire drainage area, by the ratio of the section length of collector and interceptor lines to the total length of collector and interceptor lines. An infiltration rate is computed from the input rainfall intensity and the rainfall-infiltration relationship developed from data on the 24th Street study area shown graphically by Figure 19. The flow due to storm water infiltration in each section of line is then computed by multiplying the infiltration rate by the length of collector and interceptor lines contributing to the flow in each particular line section. Beginning at the upstream end of the area, the flow in the first line section is computed by adding the infiltration flow to the dry weather flow. This flow is compared with the capacity of the line to determine if an overflow condition exists at the upstream manhole. If the flow exceeds the line capacity, the overflow rate is the difference between the computed flow and computed capacity. The volume of overflow at the manhole is computed by multiplying the overflow rate by the duration of the storm. The program analyzes each succeeding downstream line section in the same manner. The printout from the program gives, for each line section, the line capacity, the dry weather flow, the total flow in the line, the overflow rate at the upstream manhole and the volume of overflow at the upstream manhole. The program will also print out the total pounds of BOD from the overflow if a BOD concentration is furnished as input to the program. Totals for the entire interceptor are given at the end of the printout.

The computer program abstract, the source program listing and operating instructions are included in Appendix V.

OVERFLOWS IN STUDY AREAS

The computer analysis technique was used to determine the relationship between rainfall intensity and the rate of sanitary sewage overflow for the total length of interceptor in the three study areas, rate of sanitary sewage overflow being the rate at which the excess sewage exits the system once the line capacity has been exceeded. These relationships are shown by Figure 20. Two relationships are shown for the Murray Run area, one based on the capacity of the sewer in its present root-infested condition and another based on the capacity of the line in a clean condition.

FIGURE 19 RELATIONSHIP OF SANITARY SEWER INFILTRATION RATE TO AVERAGE RAINFALL INTENSITY



Through use of these relationships in conjunction with average yearly rainfall data for Roanoke, the annual sanitary sewage overflow was estimated for the three study areas. The average yearly rainfall data are based on five years of climatological data from U. S. Weather Bureau and are shown in Table 21. The estimated annual volumes of overflow caused by storm water infiltration in the three areas are as follows:

- Murray Run - 8 million gallons
- Trout Run - 23 million gallons
- 24th Street - 4 million gallons

The annual overflow volume estimated for the Murray Run sewer is based on its present capacity with root infestation.

Table 22 shows the minimum rainfall intensity that will result in overflow in each of the study areas. The table also shows the number of times overflows can be expected to occur in each area annually.

In the 24th Street study area, a rainfall intensity of 0. 11 inch per hour will create an overflow situation in the sewer. Analysis of rainfall data from the past five years shows that hourly rainfall intensities greater than 0. 11 inch per hour occur more frequently during the summer months than during the winter months. Of the total number of hourly intensities greater than 0. 11 inch per hour, approximately 75 percent were recorded during the months of May through October, which is the period of the year when the dissolved oxygen and stream flows are likely to be at a minimum.

Because of its restricted capacity, the Murray Run sewer overflows during very low intensity rainfalls. Figure 20 shows, however, that if the roots were removed, thereby increasing the line capacity, the overflow for a given rainfall intensity would decrease considerably. The minimum rainfall intensity that causes overflow would increase from 0. 07 inch per hour to 0. 17 inch per hour. As a result, the estimated number of annual overflows would decrease from 28 to 7 and the estimated annual volume of sewage overflow would decrease from 8 million gallons to 2 million gallons.

FIGURE 20 RELATIONSHIP OF RAINFALL INTENSITY TO RATE OF OVERFLOW FROM SANITARY SEWERS

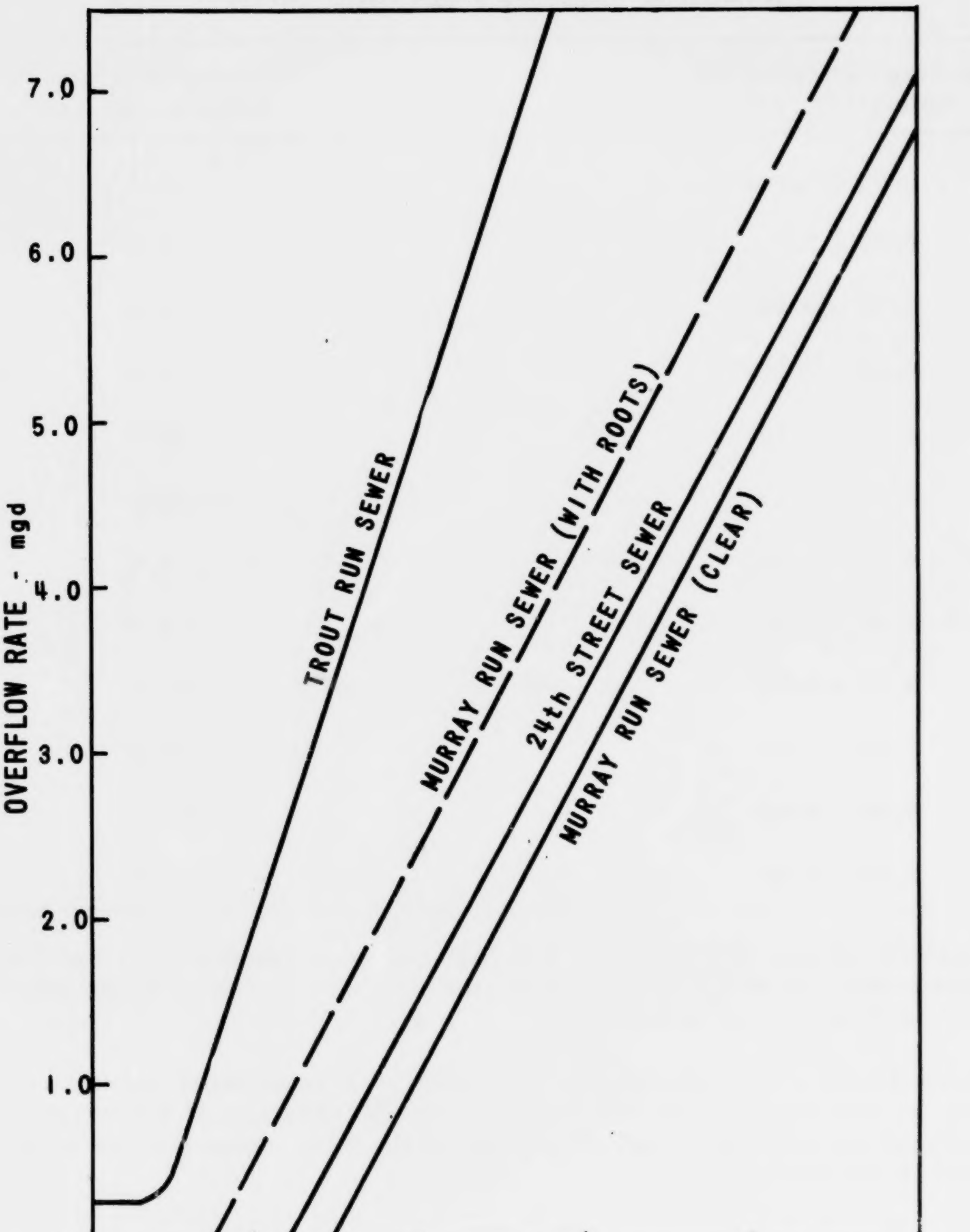


TABLE 21

AVERAGE YEARLY RAINFALL DATA

Average Intensity Of Rainfall (in./hr.)	Number of Hours Of Rainfall Per Year
0.50 or greater	1.8
0.40 - 0.50	1.2
0.30 - 0.40	3.0
0.20 - 0.30	7.8
0.15 - 0.20	29.8
0.10 - 0.15	49.2
0.09 - 0.10	5.8
0.08 - 0.09	23.6
0.07 - 0.08	23.2
0.06 - 0.07	44.4
0.05 - 0.06	46.0
0.04 - 0.05	74.4

Table 22 shows that the Trout Run Sewer surcharges from dry weather flow alone. In addition, there are an average of 99 rainfalls annually and each causes some overflow.

Table 23 shows the maximum single overflows expected to occur annually in each of the three study areas. These maximum single events account for between 12 and 19 percent of the total annual volume of overflow in the study areas.

TABLE 22

OVERFLOW FREQUENCY DATA

Study Area	Minimum Rainfall Intensity to Cause Overflow (in. /hr.)	Number of Overflows Per Year
Murray Run *	0.07	28
Trout Run **	0.00	99
24th Street	0.11	15

* Based on present restricted conditions.

** Trout Run sewer surcharges from dry weather flow, thus any amount of rainfall will result in potential overflow.

TABLE 23

MAXIMUM SINGLE OVERFLOWS IN STUDY AREAS

Study Area	Maximum Annual Overflow (mg)	Percent of Total Annual Overflow Volume
Murray Run	1.20	16
Trout Run	2.69	12
24th Street	0.75	19

POLLUTION FROM OVERFLOWS

The average pollutional characteristics of the sanitary sewage overflows in the three study areas are given in Table 24. Comparison of the overflow and dry weather concentrations shown in Table 25 reveals that the concentration of all constituents, except total solids and settleable solids are greater in the dry weather flow. The reduction in concentration of the constituents during overflows is obviously caused by dilution from storm water.

Through use of sampling data from the Trout Run stream for 24 March, 23 July and 3 August, when sewage overflows were actually observed, an attempt was made to correlate computed pollutional loads with measured pollution loads. The relationships are given in Table 26.

Since it is known that the sewer in the Trout Run area was clogged during the 24 March storm, the 22/23 July and 3 August storms are taken to be representative of the relationship between computed and actual overflow volumes. The average ratio of measured BOD from overflow to computed BOD from overflow is 0.26. This means that on these dates approximately 25 percent of the computed overflow, or that amount by which the line capacity was exceeded, actually reached the stream, the reason being the types of overflows that existed. Overflows that did occur were generally spread out over the entire interceptor line. When the pipe line capacity was exceeded, the excess flow exited by manholes, small breaks in lines and other ways not visible. Some of the overflow found its way into nearby streams; however, a larger portion either remained on the surface of the ground near a manhole or was stored underground and either re-entered the sewer or percolated into the ground.

The average concentrations given in Table 24 were used to compute the maximum annual pollutional load caused by overflow from a single rainfall event in each study area. Table 27 shows that maximum single annual overflow in the Trout Run interceptor contributes approximately 1100 pounds of BOD to the stream. This amount of BOD is approximately equivalent to the amount in the daily untreated sewage from a population of 5500 persons or about 50 percent of the population in the study area.

The estimated total annual pollution contributed to watercourses from the overflows in the study areas is given in Table 28. Although the annual amounts of pollutional constituents shown in Table 28 do not appear to represent any formidable pollutional force, the overflows from the heavy rainfalls contribute large "shock" loads of pollution. The watercourses cannot easily recover from this type of pollutional loading. These shock loads of pollution are not always diluted by increased flow in the receiving stream, Roanoke River. Many overflows occur due to thunderstorms that occur only over parts of the watershed and do not appreciably affect the daily or the mean monthly river flow. This was illustrated during the 22/23 July and 3 August storm events when the daily flow in the river was 418 and 308 cfs, respectively, well below the average of 501 cfs.

TABLE 24

AVERAGE CONCENTRATIONS OF POLLUTIONAL CONSTITUENTS OF SANITARY SEWAGE OVERFLOWS IN STUDY AREAS

Study Area	BOD (mg./l.)	Total Solids (mg./l.)	Volatile Solids (mg./l.)	Suspended Solids (mg./l.)	Volatile Suspended Solids (mg./l.)	Settleable Solids (ml./l.)
Murray Run & 24th Street	115	425	200	75	40	10
Trout Run	199	917	408	149	79	13

TABLE 25

AVERAGE CONCENTRATIONS OF POLLUTIONAL CONSTITUENTS OF DRY WEATHER SANITARY SEWAGE FLOW IN STUDY AREAS

Study Area	BOD (mg./l.)	Total Solids (mg./l.)	Volatile Solids (mg./l.)	Suspended Solids (mg./l.)	Volatile Suspended Solids (mg./l.)	Settleable Solids (ml./l.)
Murray Run	181	476	241	91	40	9
24th Street	192	616	325	113	53	6
Trout Run	342	890	473	200	98	8

TABLE 26

COMPUTED AND MEASURED BOD FROM TROUT RUN SEWER OVERFLOWS

Rainfall	Measured BOD From Stream Sampling (lbs.)	Computed BOD (lbs.)	Ratio Measured/Computed
24 March	965	860	1.12
22/23 July	227	1060	0.21
3 August	308	980	0.31

TABLE 27

POLLUTIONAL LOAD FROM MAXIMUM SINGLE ANNUAL OVERFLOW EVENT

Study Area	BOD (1000 lbs.)	Total Solids (1000 lbs.)	Volatile Solids (1000 lbs.)	Suspended Solids (1000 lbs.)	Volatile Suspended Solids (1000 lbs.)
Murray Run	0.3	1.1	0.5	0.2	0.1
24th Street	0.2	0.7	0.3	0.1	0.1
Trout Run	1.1	5.1	2.6	0.8	0.5

TABLE 28

ANNUAL POLLUTIONAL LOAD FROM OVERFLOWS IN STUDY AREAS

Study Area	BOD (1000 lbs.)	Total Solids (1000 lbs.)	Volatile Solids (1000 lbs.)	Suspended Solids (1000 lbs.)	Volatile Suspended Solids (1000 lbs.)
Murray Run	1.9	6.9	3.2	1.2	0.7
24th Street	1.0	3.5	1.7	0.6	0.3
Trout Run	9.5	44.0	19.6	7.2	3.8

WATER POLLUTION CONTROL PLANT

OVERFLOW

Roanoke, Virginia's Water Pollution Control Plant is a conventional activated sludge plant located adjacent to the Roanoke River near the east city limits as shown by Plate 1. Figure 21 shows a schematic flow layout of the plant facilities. The plant has a design capacity of 22 mgd; however, a wet weather flow of 30 mgd can be handled before bypassing is required. The overflow pipe is 54 inches in diameter and is located in the junction box of the Roanoke River interceptor and Tinker Creek interceptor. The Tinker Creek interceptor also carries the digester supernatant and overflow from the sludge thickener to the junction box. The junction box is located outside the comminutor room adjacent to the main building. The dry weather flow is never of such magnitude as to cause the plant to bypass, the average being about 20 mgd. However, the flow does occasionally reach and exceed 30 mgd with storm water flow, thus causing the plant to bypass untreated sewage into the Roanoke River. The overflow conditions always occur during or shortly after certain types of rainfall events. One objective of this report was to determine if any plant overflow trends could be found relative to:

1. Frequency of plant overflows.
2. Types of rainfall events that cause overflows.
3. Effect of the overflow from a pollutional standpoint.

FIGURE 21 FLOW DIAGRAM - WATER POLLUTION CONTROL PLANT

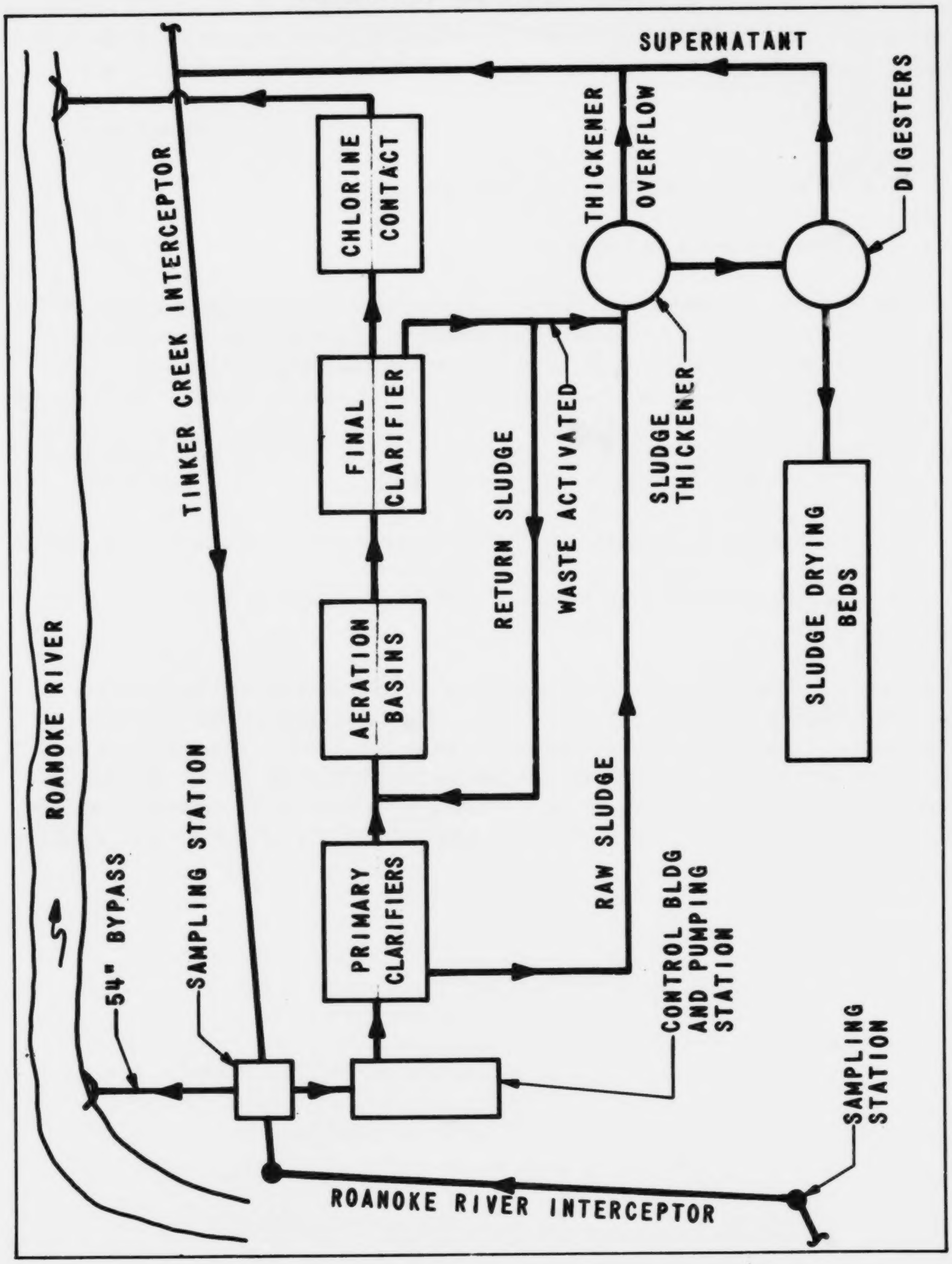

ROANOKE RIVER
54" BYPASS
SAMPLING STATION
TINKER CREEK INTERCEPTOR
CHLORINE CONTACT
FINAL CLARIFIER
AERATION BASINS
PRIMARY CLARIFIERS
RETURN SLUDGE
WASTE ACTIVATED
RAW SLUDGE
CONTROL BLDG AND PUMPING STATION
SUPERNATANT
THICKENER OVERFLOW
SLUDGE THICKENER
DIGESTERS
SLUDGE DRYING BEDS
SAMPLING STATION
ROANOKE RIVER INTERCEPTOR

Table 8, in Section 4 - Results of Investigation, shows a summary of the six overflows occurring at the plant during the study period. Figure 22 is a plot of total overflow versus total rainfall using the data collected during the six overflow events. The following is an equation of the estimated line of best fit used to describe the relationship in Figure 22.

$$T = 4.8\,R - 2.4 \qquad \text{Equation 2}$$

T = Total overflow in million gallons

R = Total rainfall in inches

To completely establish overflow frequency or trends on the basis of six overflows, all occurring during the same year, is not to be expected. However, based on Figure 22 it is shown that a linear relationship is possible between total rainfall and total overflow and, for the purpose of this report, Equation 2 was used to analyze overflows at the plant. The following limiting values were used in analyzing the overflow situation and are exemplified by Figure 22 and Table 8.

1. Minimum total rainfall to cause overflow assumed at 0.5 inch.
2. Minimum intensity to cause overflow assumed at 0.10 inch per hour.

Tables 29 through 33 give summaries of calculated overflows at the plant for the years 1964 through 1968, with all calculations based on Equation 2. Table 34 gives measured data for 1969. The rainfall data are from the Local Climatological Data, furnished by the U. S. Department of Commerce. The average annual overflow to be expected at the plant is 45 mg. Overflow will occur approximately 10 times per year.

FIGURE 2.2 RELATIONSHIP OF OVERFLOW TO RAINFALL WATER POLLUTION CONTROL PLANT

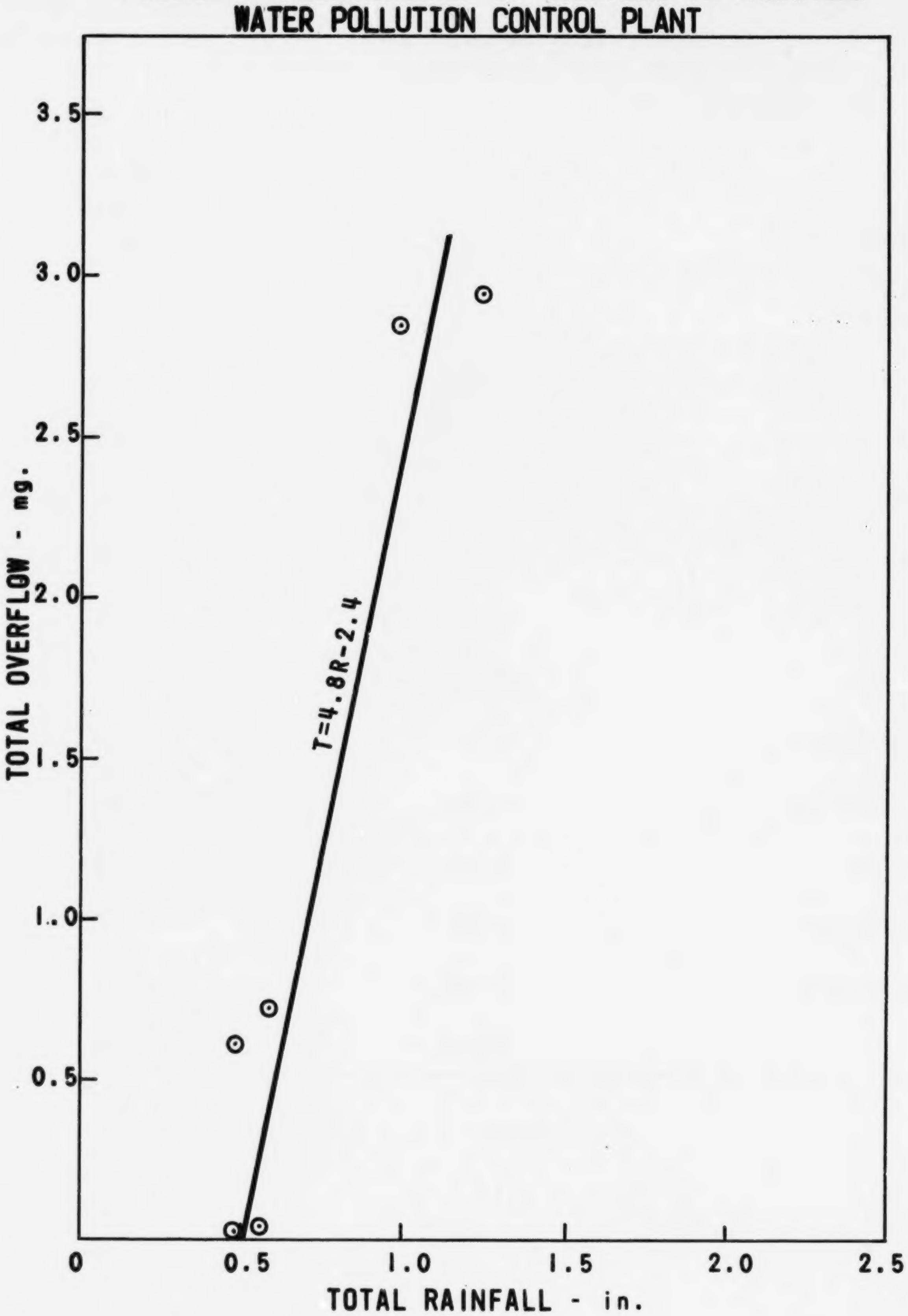


TABLE 29

CALCULATED OVERFLOWS FOR THE YEAR 1964

Date	Total Rainfall (inches)	Total Overflow (mg)
6 February	1.32	3.94
29 April	0.94	2.11
29 May	0.69	0.91
23 June	1.02	2.50
12 July	0.93	2.06
17 July	0.55	0.24
31 August	2.61	10.13
29 September	0.77	1.30
29 September	0.76	1.25
2 October	1.28	3.74
24 November	2.22	8.26
26 December	0.99	2.35
	Total	38.79

TABLE 30

CALCULATED OVERFLOWS FOR THE YEAR 1965

Date	Total Rainfall (inches)	Total Overflow (mg)
7 February	1.46	4.61
25 February	1.43	4.46
7 May	0.69	0.91
21 May	0.67	0.82
25 May	1.06	2.69
4 July	1.06	2.69
7 July	0.65	0.72
11 July	1.81	6.29
19 July	0.62	0.58
7 October	2.17	8.02
	Total	31.79

TABLE 31

CALCULATED OVERFLOWS FOR THE YEAR 1966

Date	Total Rainfall (inches)	Total Overflow (mg)
13 February	1.85	6.48
2 May	1.45	4.56
14 May	0.87	1.78
10 June	0.61	0.53
30 July	2.72	10.66
10 August	0.91	1.97
11 August	1.05	2.64
14 September	2.74	10.75
20 September	2.21	8.21
28 September	0.53	0.14
19 October	3.39	13.87
	Total	61.59

TABLE 32

CALCULATED OVERFLOWS FOR THE YEAR 1967

Date	Total Rainfall (inches)	Total Overflow (mg)
7 March	2.55	9.84
7 May	0.84	1.63
31 May	1.04	2.59
19 June	1.41	4.37
25 June	0.66	0.77
15 July	0.85	1.68
20 July	0.94	2.11
7 August	0.68	0.86
24 August	2.51	9.65
28 September	1.40	4.32
18 October	0.74	1.15
3 December	0.93	2.06
12 December	1.50	4.80
	Total	45.83

TABLE 33

CALCULATED OVERFLOWS FOR THE YEAR 1968

Date	Roanoke River Flow* (cfs)	Total Rainfall (inches)	Total Overflow (mg)
12 March	736	1.32	3.94
29 April	465	0.98	2.30
27 July	309	1.20	3.36
3 August	280	1.42	4.42
10 August	229	0.66	0.77
11 August	407	0.76	1.25
19 October	8210	6.83	30.38
		Total	46.42

* 42-year average is 501 cfs.

TABLE 34

MEASURED OVERFLOWS FOR THE YEAR 1969

Date	Roanoke River Flow* (cfs)	Total Rainfall (inches)	Total Overflow (mg)
24 March	853	1.00	2.80
21 June	319	1.25	2.90
19 July	212	0.50	0.60
22, 23 July	418	0.60	0.70
3 August	308	0.50	0.04
5 August	334	0.50	0.02
		Total	7.06

* 42-year average is 501 cfs.

Table 35 shows that about 77 percent of the total number of overflows expected annually will occur between May and October. Of the total annual volume that can be anticipated, 75 percent will occur during the same period. These same months also correspond to the time of year when the dissolved oxygen in the Roanoke River is at a minimum for the year.

TABLE 35

SUMMARY OF CALCULATED OVERFLOWS

WATER POLLUTION CONTROL PLANT

1964 THROUGH 1968

Month	Percent of Total Number of Overflows	Percent of Total Volume of Overflows
January	0	0
February	8	9
March	4	6
April	4	2
May	15	7
June	8	4
July	19	14
August	15	14
September	11	11
October	9	25
November	2	4
December	5	4
Totals	100	100

POLLUTANT

To evaluate the effect of the plant digester supernatant and overflow from the sludge thickener discharging into the junction box of the overflow pipe, samples were taken in an upstream manhole along the Roanoke River Interceptor and at the junction box during an overflow event at the plant. Figure 21 shows the relative location of the two sampling points. Tables 10 and 11, in Section 4 - Results of Investigation, show data which permit a comparison of sampling characteristics obtained at the two locations during the 22/23 July 1969 rainfall event. The samples indicate that the pollutants at the overflow pipe are considerably more concentrated than that in the interceptor. The coliforms, however, show a decrease in the junction box as compared to the samples taken in the interceptor. This is apparently due to the chlorine that is added when overflow occurs. The separation of the digester supernatant and overflow from the sludge thickener from the present overflow junction box would reduce the BOD concentration during overflow conditions, possibly by 50 percent.

Table 9, in Section 4 - Results of Investigation, shows the pounds of pollutant expected from a total rainfall of 0.6 inch. Using a 0.2 pound of BOD per capita per day, the 1192 pounds of BOD deposited into the Roanoke River during the 22/23 July rainfall event is approximately equivalent to 6000 persons discharging untreated sewage into the river for a day.

OVERFLOWS FROM ROANOKE SEWERAGE SYSTEM

Pollution of surface waters from the sanitary sewerage system can come from three possible sources: overflow from interceptors and trunk lines, overflow at the Water Pollution Control Plant, and treated plant effluent. An evaluation of overflow from interceptors in the three study areas was made and provides a basis for analysis of overflow from interceptors and trunk sewers in the entire system by correlation to the study areas. This analysis can be used, together with additional data, to evaluate the total pollutional effect to surface waters from all three possible sources of pollution.

As described previously, the study areas were selected to be representative of other areas within the entire City, so as to enable the remaining drainage areas to be classified in accordance with a study area. It was determined that the drainage areas in the City could be related to a study area, in regard to pollution of surface waters due to sanitary sewer overflows, based on the following two criteria:

1. Ratio of pipe capacity to dry weather flow (DWF).

2. Proximity of the sanitary sewer to a stream.

In regard to the first criterion, all sewers with capacities less than two times DWF will have overflows similar to the Trout Run interceptor sewer. All sanitary sewers with capacities greater than two times DWF will have overflows similar to the 24th Street and Murray Run interceptors.

As described hereinbefore, approximately 25 percent of the computed overflow actually reaches an adjacent stream. This is generally true where a stream parallels an interceptor. If there is no adjacent stream to an interceptor, the quantity of pollution from overflows reaching any stream would be minimal. The three study areas all had adjacent streams. Table 36 shows a breakdown of the City's drainage areas and their subsequent classification according to capacity in relation to dry weather flow and proximity to streams. Table 37 shows a summary of overflow conditions in the study areas and at the Water Pollution Control Plant.

Table 38 and Figure 23 show average annual BOD deposited in the Roanoke River due to overflows from interceptors and trunk sewers, Water Pollution Control Plant overflow and plant effluent.

The volume of sewage from the plant overflow structure of 45 mg was based on an average of the expected overflows. The pounds of BOD were arrived at by using a strength of 240 mg./l. for BOD as indicated in Table 10, Section 4 - Results of Investigation.

An evaluation of the annual overflow situation does not give a very complete description of the conditions that could prevail. The severity of the problem can possibly be shown by an evaluation of overflow conditions during a rainfall event. The event chosen was one that occurred on 23 August 1967. It rained for 17 hours at an intensity of 0.12 in./hr., giving a total rainfall of 2.04 inches. This particular type rainfall can be expected to occur approximately once a year.

Table 39 and Figure 24 show approximate quantities of sewage and BOD deposited in the Roanoke River during the 23 August 1967 rainfall event from the Water Pollution Control Plant effluent, the Water Pollution Control Plant overflow and the sanitary sewer interceptor and trunk sewer overflows.

TABLE 36

CLASSIFICATION OF SEWER DRAINAGE AREAS

Capacity Under 2 x DWF With Adjacent Stream	Annual DWF (mg)	Capacity Over 2 x DWF With Adjacent Stream	Annual DWF (mg)	Areas With No Stream	Annual DWF (mg)
Trout Run	383	24th Street	278	Franklin Road	146
Lick Run	296	Murray Run	154	South Roanoke	146
Grandin Road	252	Garden City	453	Williamson Road	422
Norfolk Ave.	1100	Mud Lick	325		
Tinker Creek	675	Peters Creek	230		—
Totals	2706		1440		714

TABLE 37

SUMMARY OF OVERFLOW CONDITIONS

Area	Minimum Rainfall To Cause Overflow		Number Of Annual Overflows	Total Annual Overflows (mg)	Maximum Single Annual Overflow (mg)	Annual Rainfall Events Causing Overflows (percent)
	Intensity (in./hr.)	Total (in.)				
Pollution Control Plant	0.10	0.50	10	45.00	8.37	10
24th Street	0.11	0.11	15	3.97	0.75	15
Murray Run	0.07	0.07	28	7.79	1.20	28
Trout Run	0.00	0.00	99	22.99	2.69	100

TABLE 38
AVERAGE ANNUAL BOD CONTRIBUTED TO THE ROANOKE RIVER BY SANITARY SEWAGE

SOURCE OF BOD	SEWAGE VOLUME	PERCENT OF TOTAL	POUNDS OF BOD	PERCENT OF TOTAL
POLLUTION CONTROL PLANT EFFLUENT	7,300 MG	98.4	2,192,000	91.6
POLLUTION CONTROL PLANT OVERFLOWS	45 MG	0.6	90,000	3.8
SANITARY SEWER OVERFLOWS	79 MG	1.0	111,000	4.6
TOTALS	7,424 MG	100.0	2,393,000	100.0

FIGURE 23 AVERAGE ANNUAL BOD CONTRIBUTED TO THE ROANOKE RIVER BY SANITARY SEWAGE

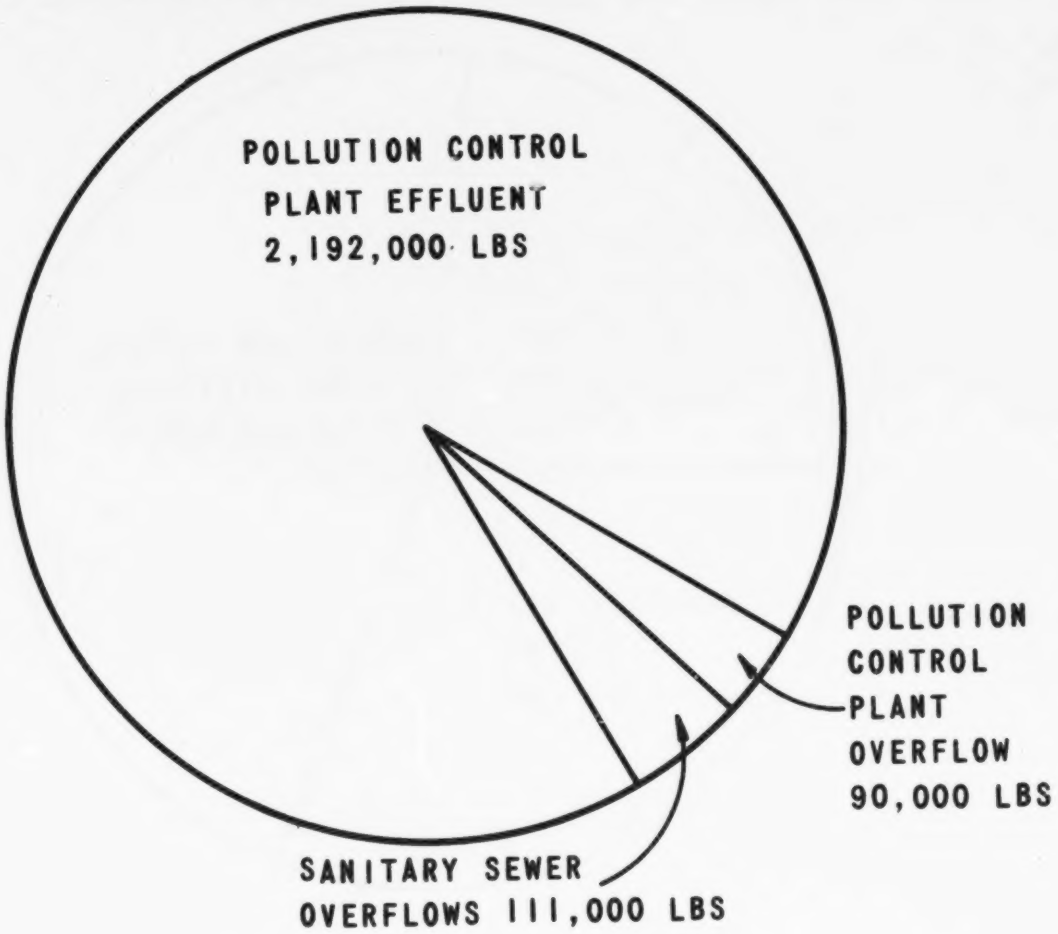
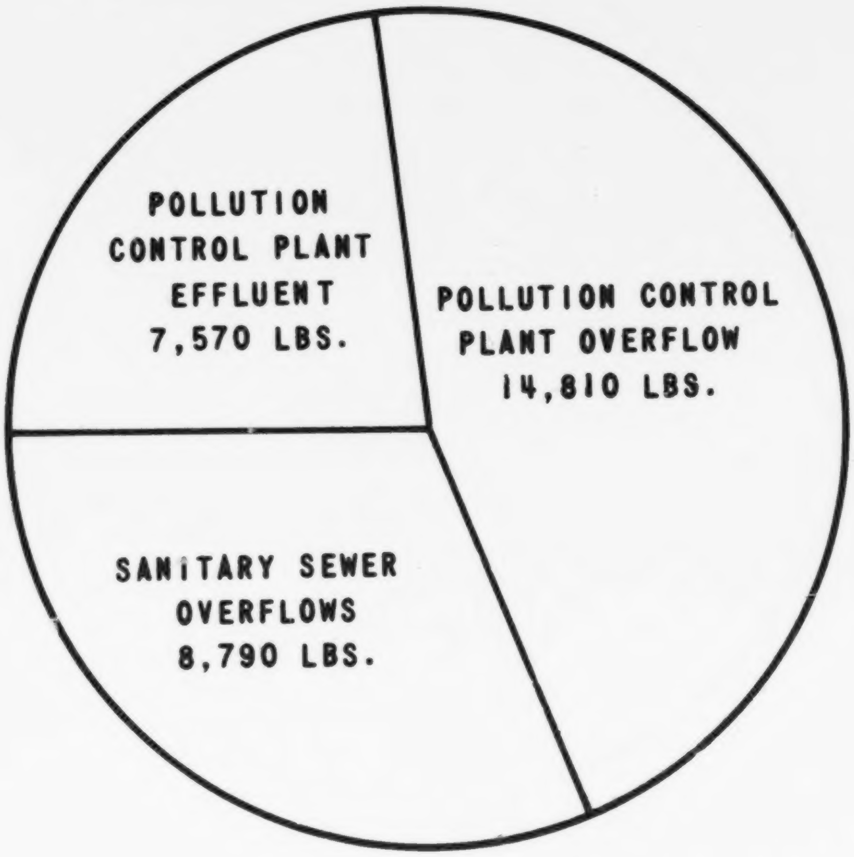


TABLE 39

BOD CONTRIBUTED TO ROANOKE RIVER BY SANITARY SEWAGE DURING MAXIMUM YEARLY RAINFALL EVENT

SOURCE OF BOD	SEWAGE VOLUME	PERCENT OF TOTAL	POUNDS OF BOD	PERCENT OF TOTAL
POLLUTION CONTROL PLANT EFFLUENT	27.5 MG	66.9	7,570	24.3
POLLUTION CONTROL PLANT OVERFLOW	7.4 MG	18.0	14,810	47.5
SANITARY SEWER OVERFLOWS	6.2 MG	15.1	8,790	28.2
TOTALS	41.1 MG	100.0	31,170	100.0

FIGURE 24 BOD CONTRIBUTED TO ROANOKE RIVER BY SANITARY SEWAGE DURING MAXIMUM YEARLY RAINFALL EVENT



The sewage volume of 27.5 mg from the pollution control plant effluent was the amount measured at the plant during the rainfall event. The pounds of BOD were calculated using a sewage strength of 220 mg./1. and 85 percent removal of BOD by the treatment processes.

A comparison between Tables 38 and 39 assesses the effect of pollution to the Roanoke River due to overflows from an individual rainfall event and annual overflows. Plant records reveal that approximately 85 percent removal of BOD can be expected by the plant. However, the plant constitutes only one part of the entire sewerage system and to completely evaluate the effectiveness of pollution abatement the entire system must be analyzed. In Table 38, 1.6 percent of the annual sewage discharge never reaches the plant, but overflows to nearby watercourses; 98.4 per cent of the system's sewage flow reaches the plant and is subjected to treatment before being discharged to the Roanoke River. However, in Table 39, 33 percent of the sanitary sewage flow never reaches the plant during a maximum yearly rainfall event and only 66.9 percent of the volume of sewage from the system reaches the plant for treatment. It is therefore concluded that overflows from individual rainfall events are significant and can amount to as much as one-third of the total sanitary sewage flow from the system.

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SECTION 6

REMEDIAL MEASURES

THE PROBLEM

The results of the hydrological investigation, gauging of streams and sewers, and water quality sampling and testing revealed that sewage overflows occur frequently in portions of Roanoke, Virginia's sanitary sewer system, resulting in a severely increased pollutional load in the City's water courses. The overflows occur during periods of rainfall and are caused primarily by excessive storm water infiltration which overloads the sewerage system. Some recurring overflows are the result of severely reduced line capacities due to tree root infestation, partial clogging with debris, broken sections of pipe, and other similar problems which can be corrected by routine maintenance procedures.

The investigations and testing also showed that the sanitary sewage flow to the Water Pollution Control Plant is increased during rainfall events and exceeds the capacity of the plant approximately ten times annually. The flow in excess of the plant capacity is mixed with the digester supernatant and sludge thickner overflow and is bypassed without treatment into the Roanoke River, thus increasing the pollutional load in the river considerably.

The investigation of remedial measures was directed at finding methods to decrease the frequency and volume of overflows.

ALTERNATE METHODS

The following methods of coping with overflows from the separate sanitary sewer system were considered:

1. **Elimination of infiltration**
2. **Additional sewer capacity**
3. **Increased treatment capacity**
4. **Detention basins**
5. **Combinations of the above**
6. **Treatment plant modifications**

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ELIMINATION OF INFILTRATION

The immediately obvious solution to eliminating overflows from sanitary sewers is to eliminate their cause which is excessive storm water infiltration. In view of the tremendous investment the City already has in its separate sewerage system, the first obvious choice is to rehabilitate and upgrade it to present recommended standards. Therefore an investigation was made into the state-of-the-art of existing sewerage repair technology and methods.

The application of television inspection and in-place grouting to locate and repair leaks has been widely used with substantial success. Austin, Texas has embarked on a regular program of inspecting and repairing 40 miles of sewers per year. Television inspection and in-place grouting with an internal packer are the key features of the program. A test conducted on 22,000 feet of pipe in Austin showed that repair of leaks and trouble spots reduced infiltration by 85 percent (5). The same method was also determined to be of value in reducing infiltration in Montgomery County, Ohio (6). The use of chemical grout to repair leaks in the City of Sadbury, Ontario, Canada sewer system was determined to be 97 percent effective (7). A sewer rehabilitation program which included cleaning, inspecting, and sealing some 25 to 28 miles of sewer was undertaken in Fort Myers, Florida. It was estimated that repairs to the sewer system reduced infiltration by 3.0 mgd at a treatment plant where normal dry weather flow should have been 2.5 mgd but often exceeded 6.0 mgd. Television inspection was used to locate leaks and chemical grout was used for repair (8). The literature study indicated that the combined use of television inspection and internal chemical grouting offers a satisfactory method of repairing sewer lines. The use of this method of repair offers several advantages:

1. It eliminates the need for excavation and pavement cuts.
2. It reduces the necessity for disturbing other services.
3. It minimizes the interruption of traffic flow.
4. It can be used successfully in sewers which are in operation.

The method does, however, have certain limitations and does not offer a "sure-fire" solution to Roanoke's infiltration problem. It has been found to be uneconomical to repair joints separated by two or more inches and impractical to repair large breaks and longitudinal cracks by this method. It also does not offer a solution to the repair of leaky laterals and connections. A review of the results of the smoke testing in the study areas revealed that a majority of the storm water entry points were on private property, probably in laterals and connections. These deficiencies would have to be corrected in the conventional manner of excavating and replacing the damaged sections. However, the locations of many of these deficiencies would be pinpointed through smoke testing and television inspection.

Another method of grouting leaks, which is applicable to the repairing of laterals as well, uses a grouting solution which sets up in cracks and breaks as a gelatinous material. The section of pipe to be repaired is plugged and filled with the grouting solution. Hydrostatic pressure is applied to the solution in the pipe forcing it out cracks and leaks. As solution is forced out of the pipe it forms a seal. The solution remaining in the pipe is pumped out and reused. This method of sewer line repair was used with apparent success in St. Augustine, Florida (9). A similar technique was used successfully in Amersham, England (10). This method of repair is not effective in sections of line that have large structural faults. Nothing definitive was found in this investigation regarding the permanency of repairs by use of grouting solutions.

A representative from the Penetryn System Incorporated, a firm experienced in sewer systems analysis and repair using the above methods, was consulted on the feasibility of making repairs to reduce infiltration in Roanoke's sewer system. His review of the results of the smoke testing and field observations in the three study areas indicated that Roanoke's problem was similar to that of other systems which had been successfully rehabilitated. It was his opinion that, through use of a carefully planned program of systematic investigation and repair, storm water infiltration in the system could be reduced by 80 percent without the use of extraordinary measures.

It is concluded that all infiltration cannot be eliminated from the system by any practical means. However, present sewer repair technology offers a feasible means of severely reducing infiltration, thereby reducing overflows. Current repair methods could be expected to reduce infiltration by 80 percent and this assumption has been used in further developing a remedial program.

ADDITIONAL SEWER CAPACITY

Interceptor and trunk sewers are normally designed for capacities of two to three times dry weather flow. Capacities sufficient to accommodate infiltration would be in the range of 8 to 10 times present dry weather flow, requiring the replacement of 70 to 80 percent of the existing interceptors. The replaced lines would be the equivalent of combined sewers which would allow entering storm water to be further polluted by mixing with sanitary sewage. Therefore, increasing sewer capacities solely to accommodate excessive infiltration of storm water is obviously not a satisfactory solution in itself.

INCREASED TREATMENT CAPACITY

Providing additional treatment capacity to treat or partially treat combined sewage is being done in many communities. However, increasing treatment capacity would only be a partial solution for eliminating pollution from overflows, as it only eliminates the plant overflows. Overflows which occur upstream in the sewerage system would be unaffected unless interceptor capacities were increased substantially to convey all infiltration to the treatment plant.

The activated sludge treatment process in Roanoke is highly susceptible to upsets from shock loads with a resultant loss of treatment efficiency. The high rates of infiltration from storms would produce such shock loadings, thereby requiring a modification of the treatment process during overflow events. The addition of tertiary treatment facilities is a distinct possibility in the future. Tertiary systems now in vogue are even more susceptible to upsets from shock loads.

DETENTION BASINS

Detention basins, lagoons, and other such methods are now in use in many localities to delay high peak discharges long enough to allow a leveling load to the sewers and the treatment plant. The prevailing use of detention basins is to receive overflows from combined sewers.

Another use of the holding tank is for treatment. The treatment may be removal of solids which are either removed and disposed of or returned to the sewerage system. The retained flow, after chlorination, is then allowed to discharge into the stream.

Such detention or holding basins are also applicable for eliminating overflows from separate sewerage systems.

The sewerage system in each of the three study areas was analyzed with the aid of computer capabilities to determine flows and overflows in the interceptor sewers for rainfalls of various intensities and durations. The computations were first made using the existing sewer line capacities and present infiltration rates. Analysis of the output showed that overflows occur in both the upper and lower regions of the three study areas. This precludes using a single basin to store overflows without increasing the capacity of portions of the existing interceptors. To use a single basin under these conditions would require replacing approximately 67 percent of the 24th Street interceptor, 78 percent of the Trout Run interceptor and 70 percent of the Murray Run interceptor, in order to contain the flow generated by a rainfall event with a one year return period.

Preventing overflows at the treatment plant further requires other holding tanks at the plant or increasing the size of the tanks in the drainage basins so that the release from the basins does not exceed the plant capacity.

The extensive increases in interceptor sewer capacity to contain the excess flows within the system so as to limit the number of detention basins required for each drainage basin, together with the relative size of the detention basin, result in a system of major proportions comparable in size to a combined storm sewer system.

COMBINATION OF ALTERNATE METHODS

No one method offered a complete solution to eliminating overflows from the sanitary sewerage system; however, each method has merits. Therefore, remedial measures incorporating the desirable features of the various methods discussed could be expected to produce the desired results.

The obvious key is to eliminate as much storm water as possible from entering the system, rather than trying to cope with it once it has been mixed with the sanitary sewage. Present repair technology indicated as much as 80 percent of this storm water can be eliminated without resorting to extreme measures. The remaining infiltration is still sufficient to produce overflows, but the smaller flow rates and volumes reduce the capacity requirements of interceptor sewers, detention basins, and treatment plants. The analysis of the system by computer permits the optimum design of all of the components.

The systems in the three study areas were analyzed, assuming that infiltration could be reduced by 80 percent through repairs to the system, and the flow and overflow computations for various rainfalls were repeated for the three interceptors. The analysis revealed that the reduction in infiltration lessened the necessity for line replacement considerably. Table 40 shows that, in order to contain the flow from the one year rainfall intensity and convey it to a single detention basin, line replacement requirements are 125 feet in the Murray Run interceptor, 500 feet in 24th Street interceptor and 6480 feet in the Trout Run interceptor. To provide enough capacity for the five and ten year intensities, line replacement requirements are much greater.

TABLE 40

SEWER LINE REPLACEMENT REQUIREMENTS
FOR USE OF A SINGLE DETENTION BASIN

INFILTRATION REDUCED 80 PERCENT

Study Area	1 Year Maximum Intensity	5 Year Maximum Intensity	10 Year Maximum Intensity
Murray Run	125'	1750'	2345'
Trout Run	6480'	12,300'	12,300'
24th Street	500'	2370'	2370'

Since overflow volume is related to both rainfall intensity and total rainfall, an investigation of overflows in the study areas from the rainfall events recorded for the past five years was undertaken to serve as a basis for determining volume requirements for detention basins. In addition, the volume must be sufficient so as to limit the downstream flow. This allowable downstream flow is the maximum hydraulic capacity of the critical downstream facility, which is the 30 mgd Water Pollution Control Plant.

Relationships were established between overflow volumes from the interceptors and the total amount of rainfall occurring at a range of intensities between the minimum intensity required to cause overflow and the maximum annual intensity. These relationships are depicted in Figures 25 through 27. The relationships were used in conjunction with the tabulation of rainfalls in the intensity range of 0.15 to 0.75 in./hr., as given in Table 41, to compute the volume of resulting overflows in the study areas. These overflow volumes are given in Tables 42 through 44. Table 45 shows the percentage of overflow events that could be detained completely by detention basins of various sizes.

Examination of Table 45 reveals that a 150,000 gallon basin in the Murray Run area would detain 91 percent of the 5 year overflow volume and reduce the number of overflows by 90 percent. Since very little increase in these percentages would result from providing larger basins, the 150,000 gallon basin appears to be the optimum size for the Murray Run area. From a similar analysis, it appears that a 200,000 gallon basin would be the optimum size for the Trout Run area and a 100,000 gallon basin would be the optimum size for the 24th Street area.

Plates 6, 7, 8, 9 and 10 show a suggested location for each detention basin and a conceptual plan for a typical basin in the Murray Run study area. The choice of a ground level or underground basin should be governed by the topographic and socio-economic characteristics of the area in which it is to be located. A ground level tank would be the less expensive of the two, but would be aesthetically undesirable in some areas.

SEPARATION OF SUPERNATANT AND OVERFLOW

The pollutional effect of bypassing sanitary sewage at the Water Pollution Control Plant can be significantly reduced by separating the digester supernatant and the overflow from the sludge thickener from the sewage overflow. This is only a partial solution to the overflow problem, but its effect could be realized immediately and would abate pollution of the Roanoke River.

FIGURE 25 RAINFALL - OVERFLOW RELATIONSHIP
MURRAY RUN STUDY AREA

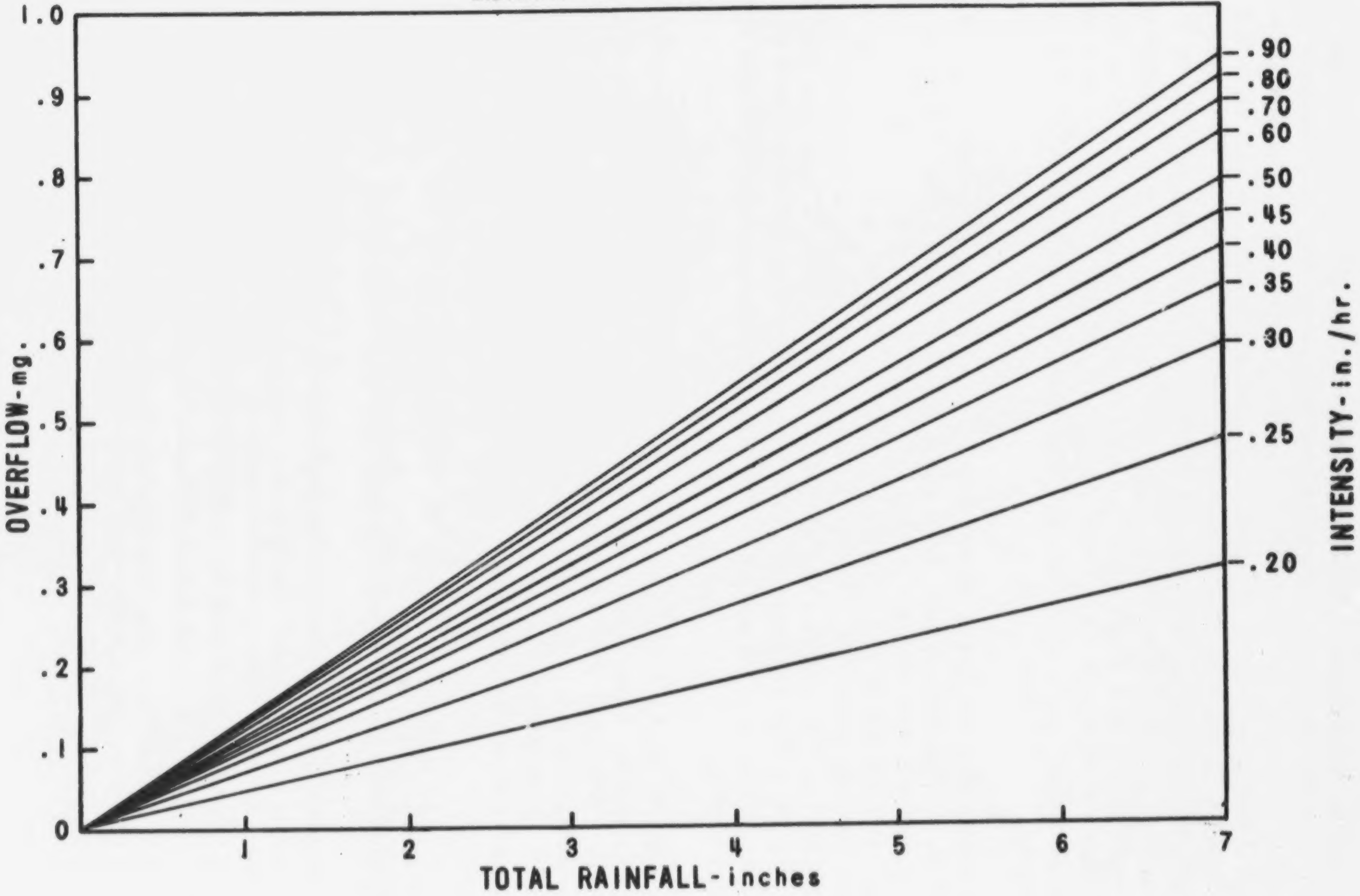


FIGURE 26 RAINFALL - OVERFLOW RELATIONSHIP
TROUT RUN STUDY AREA

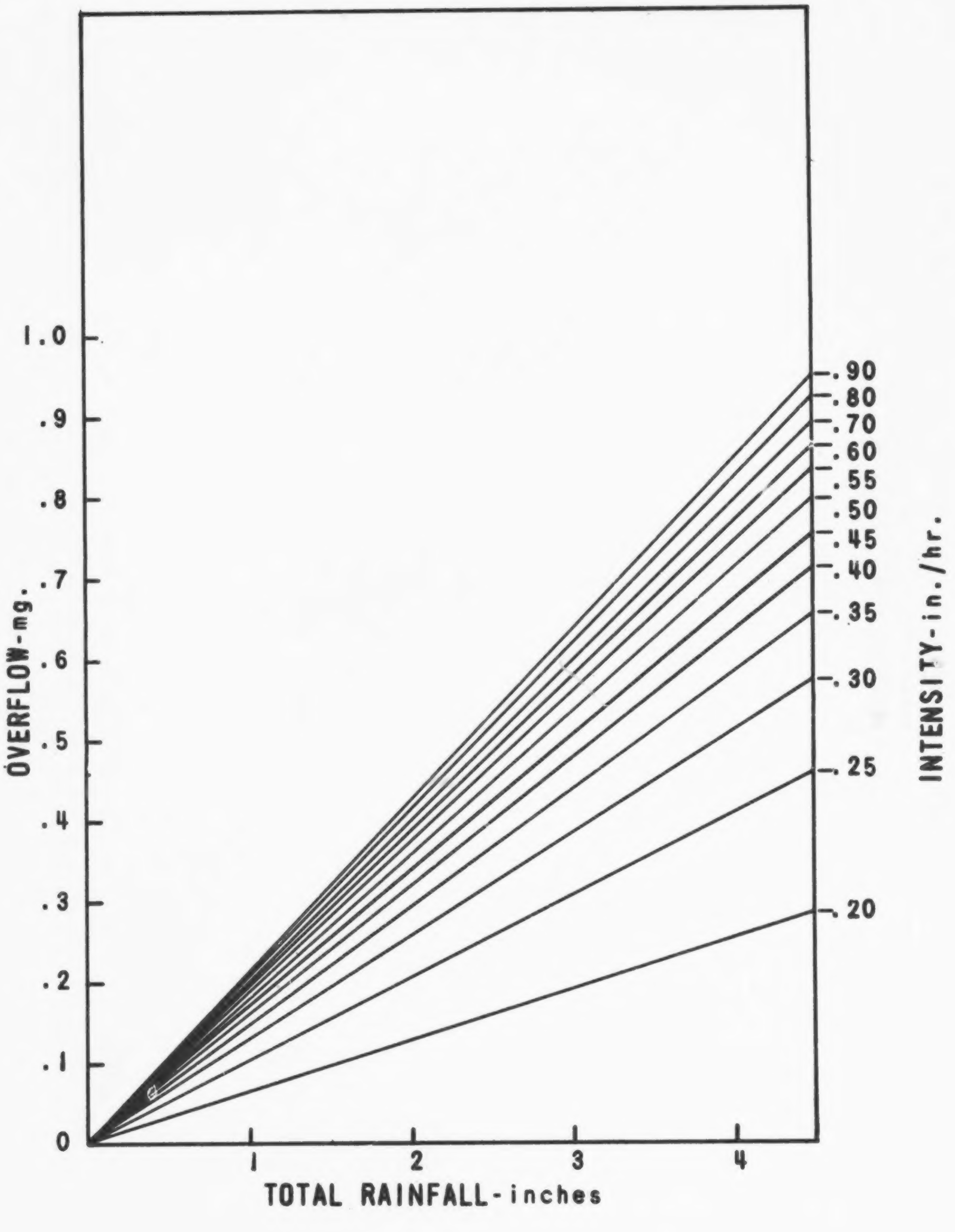


FIGURE 27 RAINFALL - OVERFLOW RELATIONSHIP
24TH STREET STUDY AREA

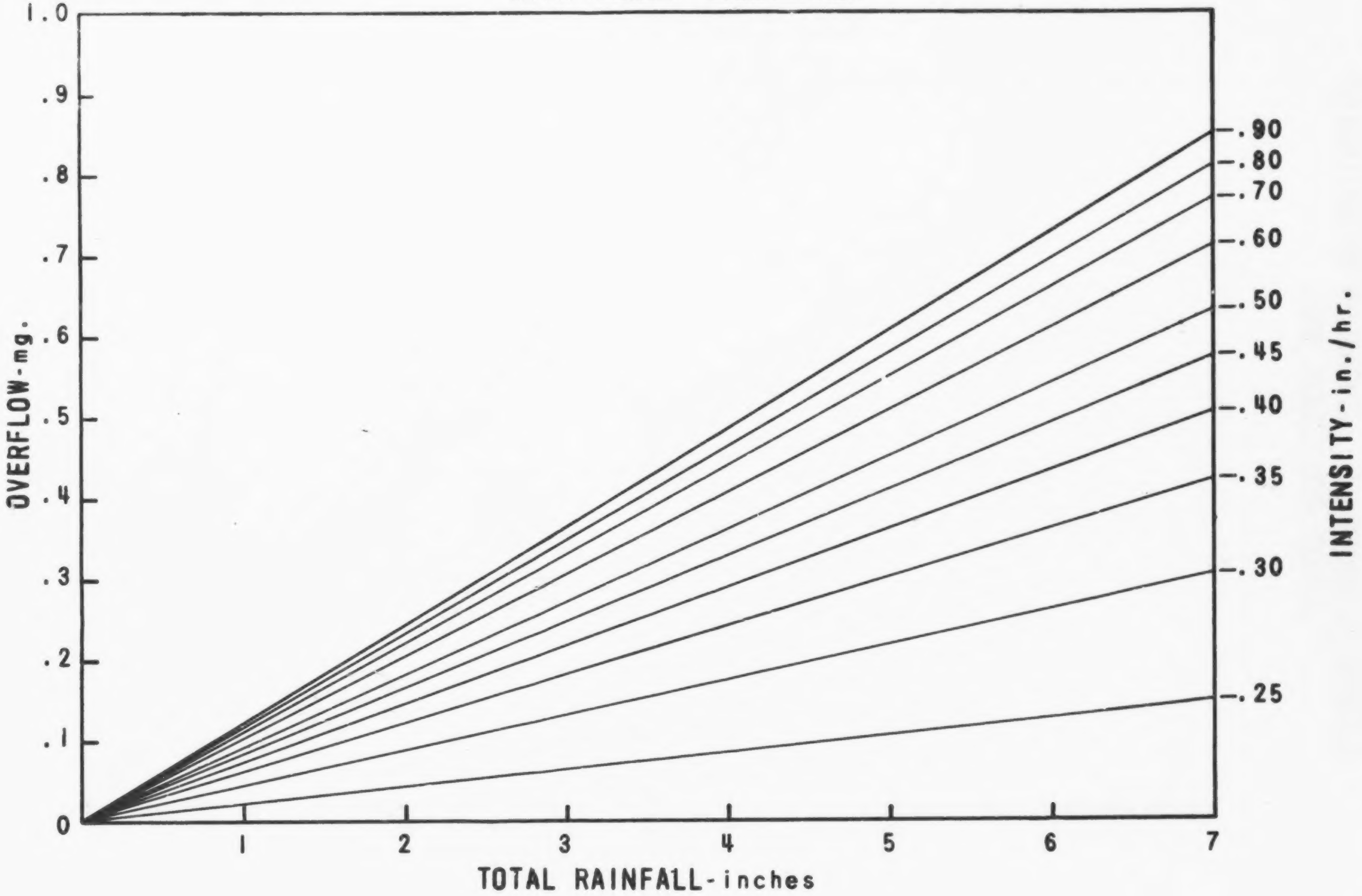


TABLE 41

TABULATION OF RAINFALL EVENTS BY TOTAL RAINFALL AND AVERAGE INTENSITIES USING FIVE YEARS OF CLIMATOLOGICAL DATA

Total Rainfall (in.)	Average Intensities (in./hr.)									
	.15-.20*	.21-.25	.26-.30	.31-.35	.36-.40	.41-.45	.46-.50	.51-.55	.56-.60	.61-.75
0.0 - 0.5	7	5	3	0	1	2				
0.5 - 1.0	6	1	3	4	0	1	1	1		
1.0 - 1.5	1	0	2	0	1	0	0	1	0	1
1.5 - 2.0	0	0	0	0	0	0	0	0	1	
2.0 - 2.5	2									
2.5 - 3.0	1	0	1							
3.0 - 3.5	1									
3.5 - 4.0	0									
4.0 - 4.5	0									
4.5 - 5.0	0									
5.0 - 5.5	0									
5.5 - 6.0	0									
6.0 - 6.5	0									
6.5 - 7.0	1									

*Events with intensities less than 0.15 in./hr. omitted due to 80 percent reduction of infiltration

TABLE 42

OVERFLOWS BASED ON FIVE YEARS OF CLIMATOLOGICAL DATA

MURRAY RUN STUDY AREA

Rainfall Interval (in.)	Intensity Range (in./hr.)	Number of Events	Overflows (mg)	
			Individual Event	Total
0.0 - 0.5	.15 - .20*	7	.020	.140
	.21 - .25	5	.025	.125
	.26 - .30	3	.040	.120
	.36 - .40	1	.048	.048
0.5 - 1.0	.15 - .20	6	.043	.258
0.0 - 0.5	.41 - .45	2	.055	.110
0.5 - 1.0	.21 - .25	1	.065	.065
1.0 - 1.5	.15 - .20	1	.068	.068
0.5 - 1.0	.26 - .30	3	.083	.249
	.31 - .35	4	.091	.364
	.41 - .45	1	.108	.108
	.46 - .50	1	.110	.110
	.51 - .55	1	.110	.110
2.0 - 2.5	.15 - .20	2	.110	.220
1.0 - 1.5	.26 - .30	2	.124	.248
2.5 - 3.0	.15 - .20	1	.135	.135
1.0 - 1.5	.36 - .40	1	.150	.150
3.0 - 3.5	.15 - .20	1	.160	.160
1.0 - 1.5	.51 - .55	1	.170	.170
	.71 - .75	1	.190	.190
2.5 - 3.0	.26 - .30	1	.250	.250
6.5 - 7.0	.15 - .20	1	.310	.310

*Events with intensities less than 0.15 in./hr. omitted due to 80 percent reduction of infiltration

TABLE 43

OVERFLOWS BASED ON FIVE YEARS OF CLIMATOLOGICAL DATA

TROUT RUN STUDY AREA

Rainfall Interval (in.)	Intensity Range (in./hr.)	Number of Events	Overflows (mg)	
			Individual Event	Total
0.0 - 0.5	.15 - .20*	7	.035	.245
	.21 - .25	5	.055	.275
0.5 - 1.0	.15 - .20	6	.065	.390
0.0 - 0.5	.26 - .30	3	.070	.210
	.36 - .40	1	.080	.080
	.41 - .45	2	.090	.180
1.0 - 1.5	.15 - .20	1	.100	.100
0.5 - 1.0	.21 - .25	1	.105	.105
	.26 - .30	3	.130	.390
	.31 - .35	4	.145	.580
2.0 - 2.5	.15 - .20	2	.160	.320
0.5 - 1.0	.41 - .45	1	.175	.175
	.46 - .50	1	.180	.180
	.51 - .55	1	.190	.190
2.5 - 3.0	.15 - .20	1	.190	.190
1.0 - 1.5	.26 - .30	2	.200	.400
3.0 - 3.5	.15 - .20	1	.220	.220
1.0 - 1.5	.36 - .40	1	.240	.240
	.51 - .55	1	.280	.280
	.71 - .75	1	.310	.310
2.5 - 3.0	.26 - .30	1	.380	.380
6.5 - 7.0	.15 - .20	1	.440	.440

*Events with intensities less than 0.15 in./hr. omitted due to 80 percent reduction of infiltration

TABLE 44

OVERFLOWS BASED ON FIVE YEARS OF CLIMATOLOGICAL DATA

24TH STREET STUDY AREA

Rainfall Interval (in.)	Intensity Range (in./hr.)	Number of Events	Overflows (mg) Individual Event	Total
0.0 - 0.5	.15 - .20*	7	.000	.000
0.5 - 1.0	.15 - .20	6	.000	.000
1.0 - 1.5	.15 - .20	1	.000	.000
2.0 - 2.5	.15 - .20	2	.000	.000
2.5 - 3.0	.15 - .20	1	.000	.000
3.0 - 3.5	.15 - .20	1	.000	.000
6.5 - 7.0	.15 - .20	1	.000	.000
0.0 - 0.5	.21 - .25	5	.010	.050
	.26 - .30	3	.020	.060
0.5 - 1.0	.21 - .25	1	.020	.020
0.0 - 0.5	.36 - .40	1	.039	.039
	.41 - .45	2	.040	.080
0.5 - 1.0	.26 - .30	3	.042	.126
	.31 - .35	4	.060	.240
1.0 - 1.5	.26 - .30	2	.065	.130
0.5 - 1.0	.41 - .45	1	.080	.080
	.46 - .50	1	.090	.090
	.51 - .55	1	.100	.100
1.0 - 1.5	.36 - .40	1	.110	.110
2.5 - 3.0	.26 - .30	1	.130	.130
1.0 - 1.5	.51 - .55	1	.150	.150
	.71 - .75	1	.170	.170

*Events with intensities less than 0.15 in./hr. omitted due to 80 percent reduction of infiltration

TABLE 45

RELATIONSHIP BETWEEN DETENTION BASIN SIZE, RAINFALL EVENTS AND VOLUME OF OVERFLOW-BASED ON FIVE YEARS OF CLIMATOLOGICAL DATA

Size of Basin (gal.)	Percent Reduction of Overflow Events in Five Years	Percent of Overflow Volume Detained in Five Years
Murray Run		
50,000	47	52
100,000	70	79
150,000	90	91
200,000	96	96
250,000	98	98
Trout Run		
50,000	15	38
100,000	53	63
150,000	70	79
200,000	87	89
250,000	92	93
300,000	96	96
24th Street		
50,000	72	65
100,000	91	90
150,000	98	99
200,000	100	100

A PROGRAM FOR CONTROLLING POLLUTION FROM SANITARY SEWER OVERFLOWS

Only a limited sampling of the overall problem of sanitary sewer overflows was possible in this study. Nevertheless this sampling should sufficiently indicate the character and magnitude of the problem and provide guidelines towards solutions not only for Roanoke but also for other communities faced with similar situations.

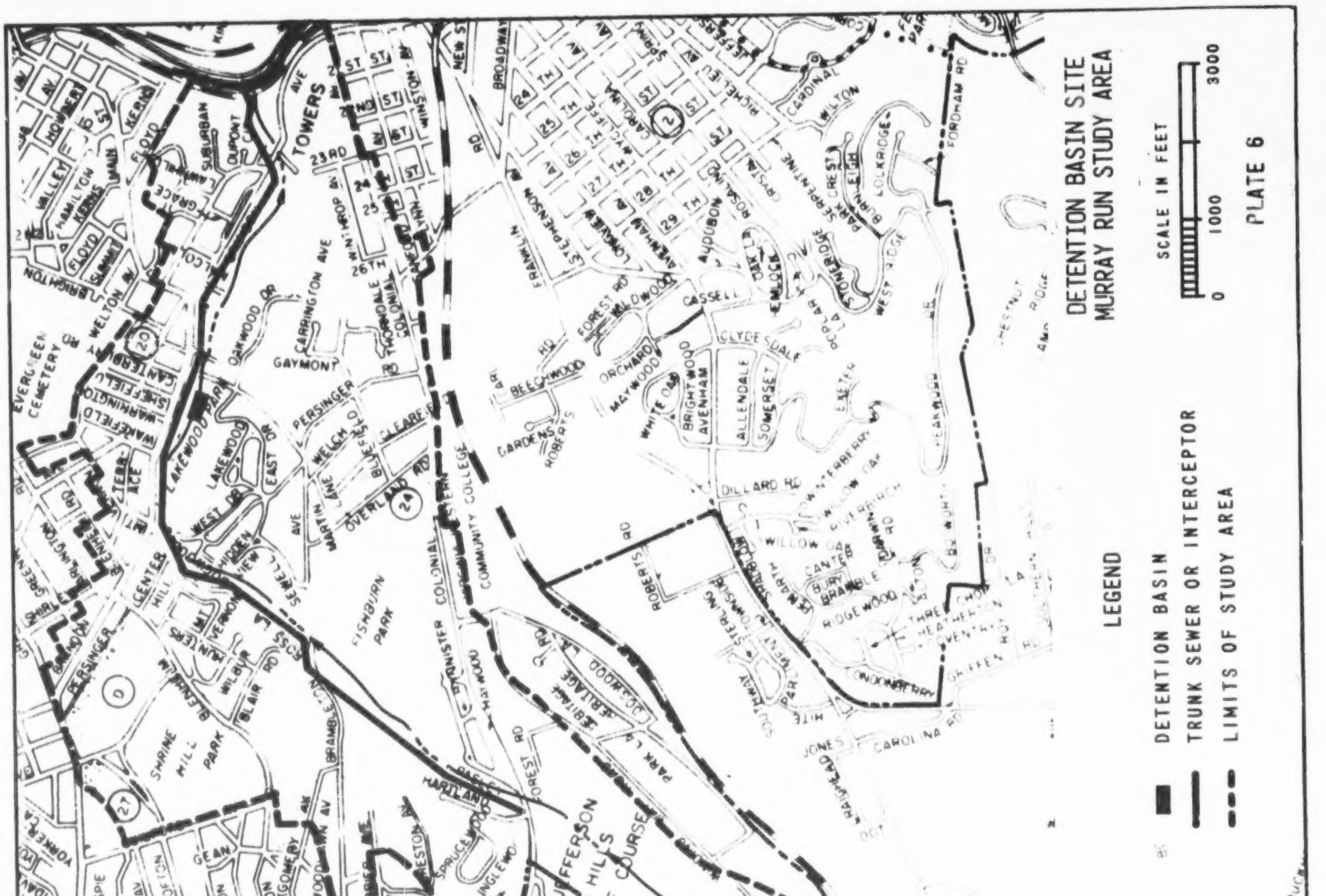
A program for a significant reduction of sewer overflows requires a combination of methods and techniques, as no one method offers a cure-all. Worthwhile improvements can only be made through a comprehensive program of renovation, repair and control measures. Relative priorities should be taken into account in the selection of areas for restoration so that the worst conditions will be remedied first. The following outline presents the major features of a restoration program.

1. Once an area has been selected for rehabilitation, the sewerage system should be visually inspected and smoke tested to locate and define major storm water entry points and to generally assess the condition of the system. This method can usually be accomplished with City forces and is fast and economical. One crew can test up to 5000 feet per day.

2. The results of such testing should be recorded with both written descriptions and photographs. Separate listings of deficiencies on private property should be made and turned over to the Building Inspector for any code enforcement. A cooperative program between the City and the private owner should be developed to simplify and speed corrections on private property.

3. From the results of the smoke testing and inspection program, obvious deficiencies should be scheduled for repair by the usual maintenance forces. This would involve cleaning lines of roots and other obstructions, replacing broken sections, removing storm water connections, sealing or raising perforated manhole covers in depressed areas, and correcting other such obvious defects.

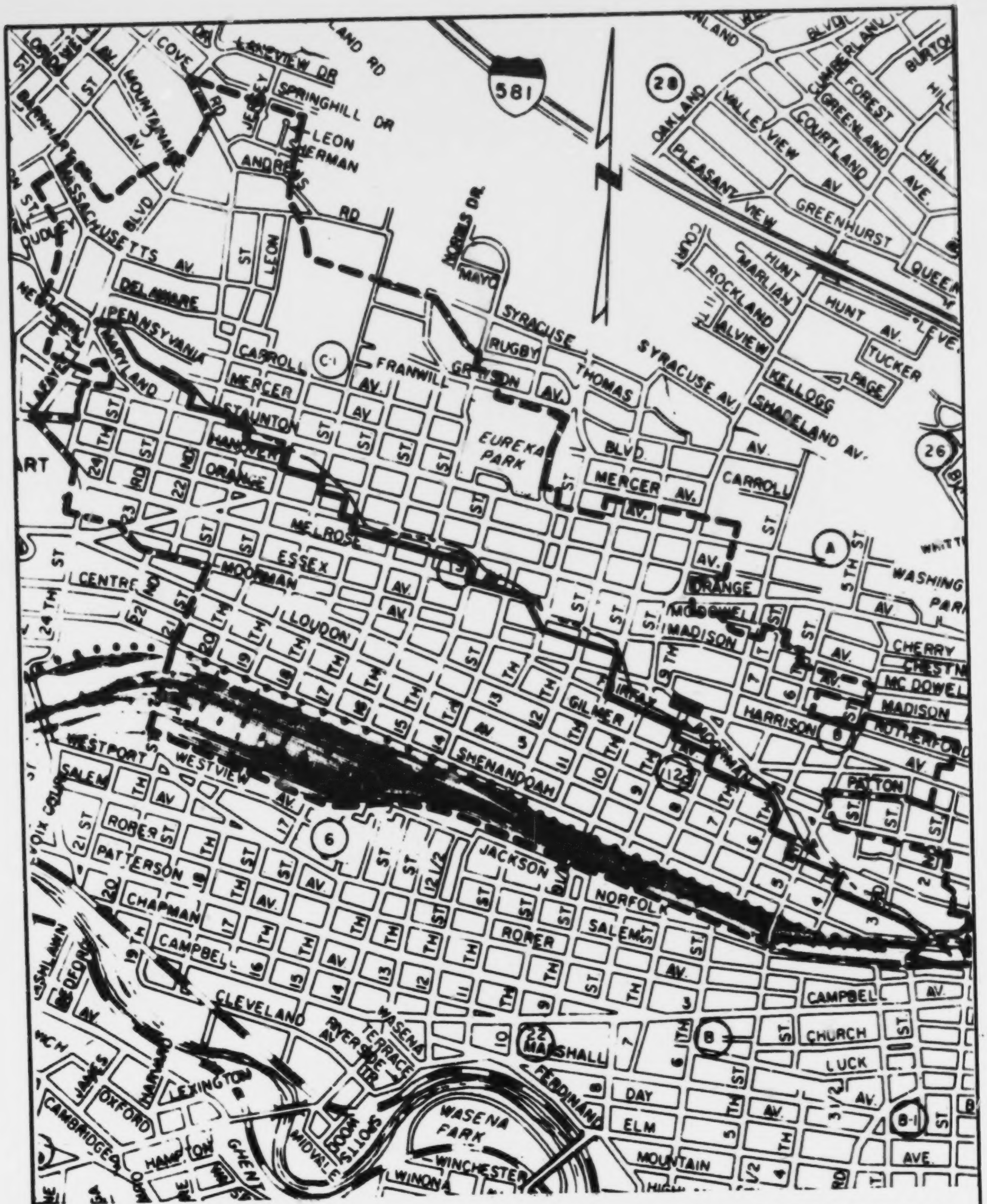
4. Smoke testing would also indicate those areas of the system where more intensive inspections by television are required. The television inspections will pinpoint defects which require excavating to repair. While the television inspection is underway, the joint sealing and grouting should be accomplished as necessary. This part of the program



DETENTION BASIN SITE
MURRAY RUN STUDY AREA

PLATE 6

LEGEND
DETENTION BASIN
TRUNK SEWER OR INTERCEPTOR
LIMITS OF STUDY AREA
SCALE IN FEET
0
1000
3000
JEFFERSON HILLS GOLF COURSE
FISHBURN PARK
SHRINE HILL PARK
EVERGREEN CEMETERY
TOWERS


581
28
26
LAKEVIEW DR
SPRINGHILL DR
LEON
SHERMAN
ANDREWS RD
COVE RD
JERSEY
MOUNTAIN AV
MASSACHUSETTS AV.
DUDLEY
DELAWARE
PENNSYLVANIA
MARYLAND
CARROLL
MERCER
STAUNTON
HANOVER
ORANGE
MELROSE
ESSEX
MOORMAN
CENTRE
LOUDON
FRANWILL AV.
GRAYSON AV.
RUGBY
MAYO
NORRIS DR.
SYRACUSE
THOMAS
SYRACUSE AV.
EUREKA PARK
BLVD.
MERCER AV.
CARROLL
ORANGE
MC DOWELL
MADISON
HARRISON
GILMER
SHENANDOAH AV
WESTPORT
WESTVIEW AV.
SALEM
ROREr
PATTERSON
CHAPMAN
CAMPBELL
CLEVELAND
JACKSON
NORFOLK
ROPER
SALEM
RIVERSIDE
WASENA TERRACE
MARSHALL
FERDINAND
DAY
ELM
MOUNTAIN
WASENA PARK
WINCHESTER
WINONA
MIDVALE
LEXINGTON
OXFORD
CAMBRIDGE
HAMPTON
CAMPBELL AV.
CHURCH
LUCK
AV.
PATTON
RUTHERFORD
MADISON
MC DOWELL
CHESTNUT
CHERRY
WASHINGTON PARK
OAKLAND
VALLEY VIEW
PLEASANT VIEW
COURTLAND
GREENLAND
FOREST
CUMBERLAND
HILL
AVE.
GREENHURST
HUNT
MARLIAN
ROCKLAND
ALVIEW
KELLOGG
SHADELAND AV.
TUCKER
PAGE
HUNT AV.
QUEEN
C-1
A
B
B-1
6
112
22

LEGEND

▬ DETENTION BASIN

— TRUNK SEWER OR INTERCEPTOR

- - - LIMITS OF STUDY AREA

DETENTION BASIN SITE
TROUT RUN STUDY AREA

SCALE IN FEET

0 1000 3000

PLATE 7

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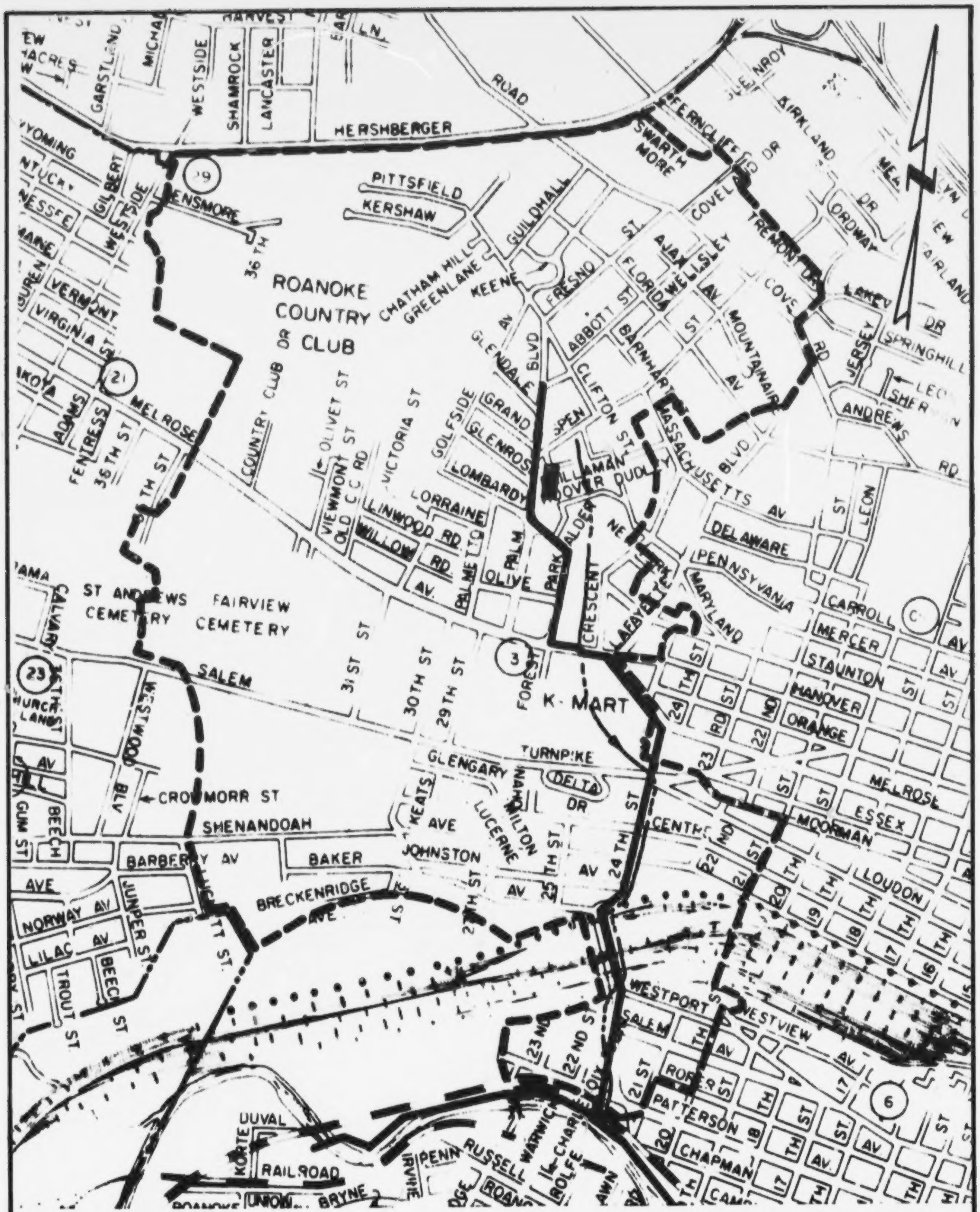
HERSHBERGER
ROAD
ROANOKE COUNTRY CLUB
PITTSFIELD
KERSHAW
36TH
COUNTRY CLUB DR
CHATHAM HILL
GREENLANE
KEENE
GUILDHALL
FRESNO
ABBOTT ST
FLORIDA
WELLSLEY
AJAX
MOUNTAINAIR AV
COVE RD
TRENOR DR
FERNCLIFF DR
SWARTHMORE
KIRKLAND
ORDWAY DR
JERSEY
SPRINGHILL
ANDREWS
MASSACHUSETTS AV
DELAWARE
PENNSYLVANIA
MARYLAND
CARROLL AV
MERCER AV
STAUNTON AV
HANOVER
ORANGE
MELROSE
ESSEX
MOORMAN
LOUDON
WESTSIDE
GILBERT
MELROSE
36TH ST
FENTRESS
ADAMS
VERMONT
VIRGINIA
ST ANDREWS CEMETERY
FAIRVIEW CEMETERY
SALEM
31ST ST
30TH ST
29TH ST
FOREST
K-MART
CRESCENT
LAFAYETTE
GLENGARY
TURNPIKE
DELTA DR
SHENANDOAH
CROWMORR ST
BARBERRY AV
BAKER
JOHNSTON
KEATS AVE
LUCERNE
BRECKENRIDGE AVE
NORWAY AV
LILAC AV
TROUT ST
JUNIPER ST
BEECH
24TH ST
CENTRE
WESTPORT
WESTVIEW AV
SALEM
ROREER ST
PATTERSON
CHAPMAN
23 ND
22 ND ST
DUVAL
KORTE
RAILROAD
PENN
RUSSELL
WARWICK
ROLFE
CHARLES
IRVINE
29
21
23
3
6

DETENTION BASIN SITE
24TH STREET STUDY AREA

LEGEND

- ■ DETENTION BASIN
- ━ TRUNK SEWER OR INTERCEPTOR
- ╍ LIMITS OF STUDY AREA

SCALE IN FEET

0 1000 3000

PLATE 8

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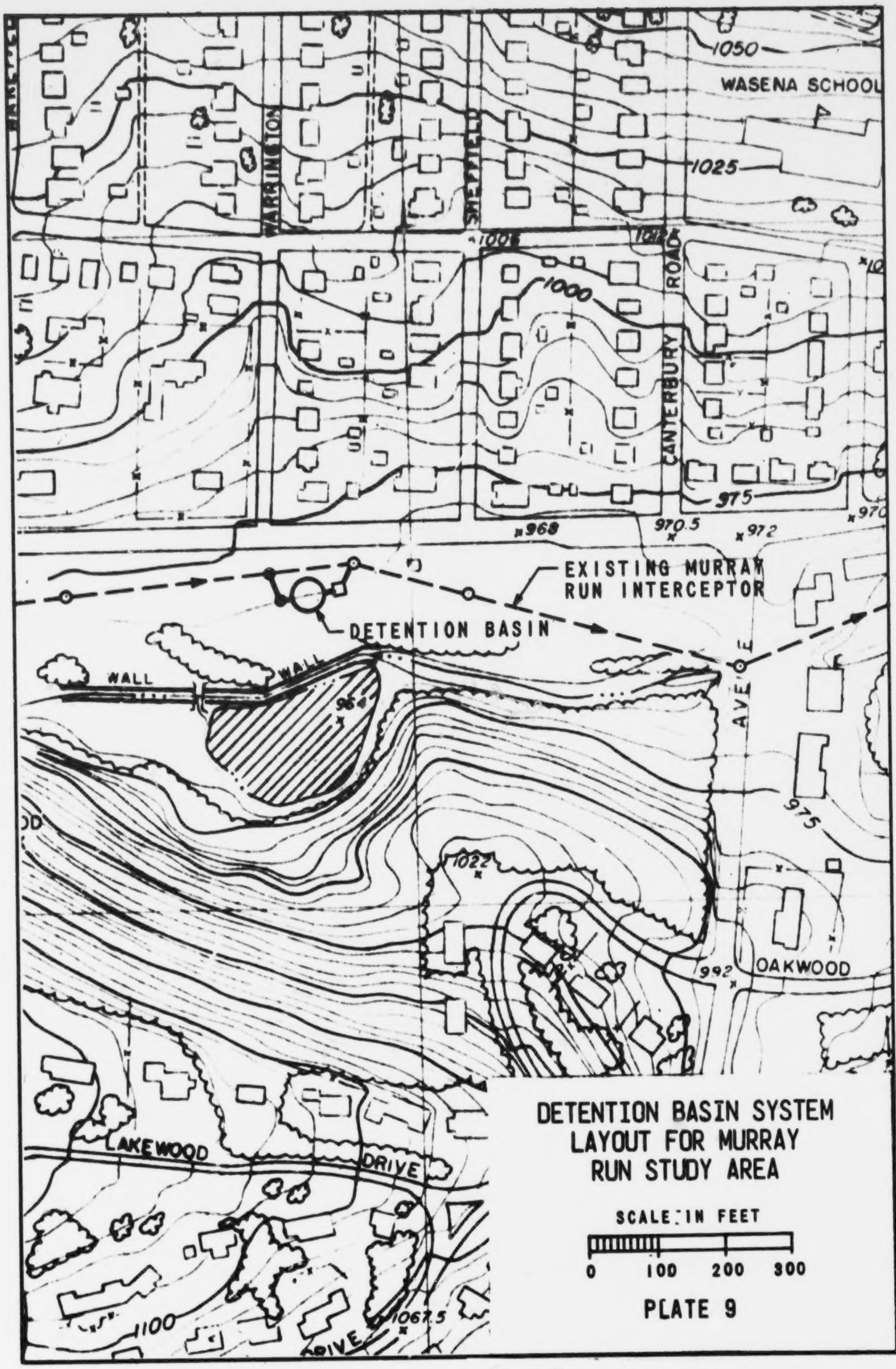
1050
WASENA SCHOOL
1025
WARRINGTON
SHEFFIELD
1005
1025
CANTERBURY ROAD
1000
975
968
970.5
972
970
EXISTING MURRAY RUN INTERCEPTOR
DETENTION BASIN
WALL
WALL
954
AVE E
975
1022
992
OAKWOOD
LAKEWOOD
DRIVE
1100
1067.5
DRIVE

DETENTION BASIN SYSTEM LAYOUT FOR MURRAY RUN STUDY AREA

SCALE IN FEET

0 100 200 300

PLATE 9

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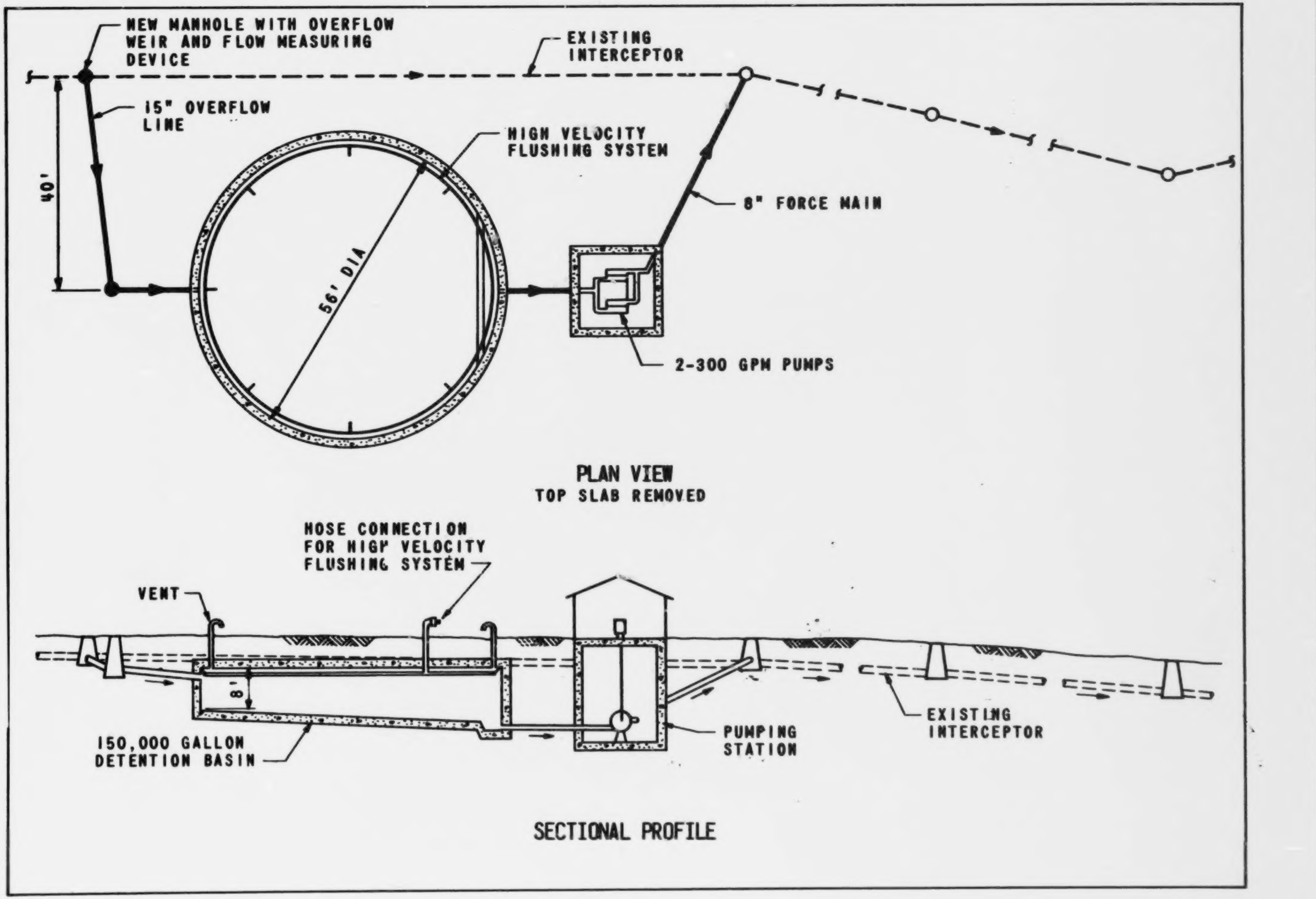
PLATE 10 DETENTION BASIN CONCEPTUAL DESIGN FOR MURRAY RUN STUDY AREA



NEW MANHOLE WITH OVERFLOW WEIR AND FLOW MEASURING DEVICE
EXISTING INTERCEPTOR
15" OVERFLOW LINE
40'
HIGH VELOCITY FLUSHING SYSTEM
56' DIA
8" FORCE MAIN
2-300 GPM PUMPS
HOSE CONNECTION FOR HIGH VELOCITY FLUSHING SYSTEM
VENT
8'
150,000 GALLON DETENTION BASIN
PUMPING STATION
EXISTING INTERCEPTOR

PLAN VIEW
TOP SLAB REMOVED

SECTIONAL PROFILE

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will require either the purchase of television inspection and grouting equipment for use by City forces or the employment of firms normally engaged in this work. This is the most expensive and variable part of the repair program as the exact extent cannot be determined beforehand.

5. Rainfall and flows in the sewers should be monitored continuously before, during and at completion of the repair work in order to evaluate the effectiveness of the repairs. An 80 percent reduction of infiltration is expected.

6. As all of the infiltration will not have been eliminated by the above program, the system should be analyzed to determine those line segments requiring replacement in order to provide adequate hydraulic capacity. The analysis will also reveal the optimum size and location of required detention basins to store peak flows.

7. The volume of a detention basin should be selected to contain the overflow resulting from at least the maximum storm event with a one year return frequency. In addition, the detention basin should limit the outflow from the drainage area so that the hydraulic capacity of the downstream facilities is not exceeded. In Roanoke's case the limiting feature is the Water Pollution Control Plant.

8. Sufficient telemetering equipment should be incorporated into the detention basin facility to permit monitoring during overflow events and to aid in the overall operation of the system.

9. The reliability of the system will only be as good as the maintenance program. Routine preventative maintenance will insure that the system operates properly during the critical storm periods.

10. Once the system has been restored, an effective routine maintenance program on a scheduled basis should be established. Connections into the system should be made only by licensed contractors and in strict compliance with codes. A stepped-up maintenance program would alleviate problems in other areas until the comprehensive sewer repair program can be undertaken.

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COSTS OF REMEDIAL MEASURES

BASIS OF COST ESTIMATES

The costs for inspecting, repairing, cleaning, and replacing sewer lines and providing detention basins are based on the results of detailed investigations undertaken in the study areas. Application of the required costs for these measures to the remaining drainage areas in the City were made according to their similarity to the study areas. The cost for sewer line replacement is the cost for new sewer line requirements in addition to those recommended in "Report on Sanitary Sewerage Interceptors and Trunk Mains, City of Roanoke, Virginia" (2). The separation of the combined sewer system in the downtown portion of the City was recommended in the report (2) and the cost for this measure was taken from the report and adjusted to reflect current construction prices.

The estimated unit costs applicable to the remedial measures are given in Table 46. The costs are considered to be those currently in effect for this type of work.

Cost estimates were made for implementation of remedial measures in the three study areas and are presented in Table 47.

COSTS OF RECOMMENDED REMEDIAL MEASURES

The estimated construction cost of recommended remedial measures for the entire City of Roanoke is given in Table 48 as $6,149,000. This cost includes repairs of the sewer system, replacement of sections of existing sewer lines, television inspection, cleaning, grouting, separation of combined sewers in a portion of the City and separation of digester supernatant and sludge thickner flow and sewage overflow at the Water Pollution Control Plant. The estimated operation and maintenance cost for 13 underground detention basins and pumping stations is $22,000 per year as shown in Table 49. Table 50 gives a breakdown of the remedial measure costs per acre and per capita for each study area and the entire City.

TABLE 46

UNIT COSTS

Item	Unit	Cost
Repair of Sewers		
Repair lateral sewer leak	Ea.	$ 250.00
Repair collector sewer leak	Ea.	500.00
Repair interceptor sewer leak	Ea.	500.00
Repair leak detected by smoke emitting from catch basin	Ea.	1,000.00
Television Inspection, Cleaning and Grouting of Interceptors and Collectors	LF	6.00
Replace Sewer Lines		
12- to 24-inch	LF	26.00
30- to 36-inch	LF	34.00
42- to 48-inch	LF	63.00
Detention Basins		
Circular underground tank with pumping station and all appurtenances		
100,000 gal.	Ea.	115,000.00
150,000 gal.	Ea.	128,300.00
200,000 gal.	Ea.	146,500.00
Property aquisition per basin	LS	10,000.00

TABLE 47

COST ESTIMATE FOR REMEDIAL MEASURES IN EACH STUDY AREA

Study Area	Repair of Sewers	TV Inspect. and Grout	Detention Basin	Replace Portions of Interceptors	Totals
Murray Run	$35,500	$210,200	$138,300	$ 3300	$387,300
Trout Run	93,000	309,200	156,500	27,000	585,700
24th Street	27,000	117,200	125,000	13,000	282,200

TABLE 48

COST ESTIMATE FOR RECOMMENDED REMEDIAL MEASURES FOR THE ENTIRE CITY OF ROANOKE

Item	Estimated Cost
Repair of Sewer System	$ 715,000
Television Inspection and Grout	2,855,600
Sewer Line Replacement	200,200
Detention Basins	1,835,700
Separation of Combined Sewers	522,500
Separation of Digester Supernatant from Overflow at Water Pollution Control Plant	20,000
Total	$6,149,000

TABLE 49

OPERATIONAL AND MAINTENANCE COSTS FOR RECOMMENDED REMEDIAL MEASURES FOR THE ENTIRE CITY OF ROANOKE

Item	Estimated Cost/Year
Clean 13 Basins After Each Rainfall Event	$ 9200
Observations During Rainfall Events	4600
Maintain Equipment	6200
Electrical Power	2000
Total	$22,000

TABLE 50

ESTIMATED COSTS PER VARIOUS UNITS FOR RECOMMENDED REMEDIAL MEASURES

Area	Total Project Cost	Cost Per Acre	Cost Per Capita
Murray Run Study Area	$ 387,300	$426	$65
Trout Run Study Area	585,700	587	53
24th Street Study Area	282,200	273	28
Entire City of Roanoke	6,149,000	370	61

BENEFITS OF REMEDIAL MEASURES

Overflows presently occur approximately 28 times per year in the Murray Run study area and 15 times per year in the 24th Street area. The Trout Run interceptor overflows during nearly every rainfall and occasionally during dry weather flow. Conditions similar to these are reported in other areas of the City. Implementation of the remedial measures listed in Table 48 will eliminate all overflows in Roanoke's sanitary sewerage system except those from very high intensity rainfalls. The volume of overflow from higher intensity rainfalls which occur less frequently than once per year will be reduced. The reduction in frequency of overflows will provide relief from the offensive and unhealthy conditions created by the frequent discharges of raw sewage into yards, into basements, onto streets and sidewalks, and into streams.

The following shows the estimated reductions in overflow volume in the study areas to be achieved by implementation of the recommended remedial measures:

ESTIMATED ANNUAL OVERFLOW VOLUME

Study Area	Existing Conditions	Improved Conditions
Murray Run	8 mg	0.3 mg
Trout Run	23 mg	0.6 mg
24th Street	4 mg	0.2 mg

For the City as a whole, it is estimated that the present 79 million gallon annual overflow would be reduced to 2.5 million gallons.

It is not within the scope of this study to determine to what extent the overflow of raw sewage from Roanoke's sewer system and the sewage bypasses at the pollution control plant contribute to the pollution of Smith Mountain Lake, which is a 20,000 acre lake four and one half miles downstream. Neither is it within the scope of the study to determine to what extent the recommended remedial measures will alleviate the polutional problem at the lake. It is judged, however, that the implementation of the remedial measures will enhance the aesthetic and recreational value of the Roanoke River arm of the lake.

SECTION 7

ACKNOWLEDGEMENTS

Appreciation is extended to the following persons and their organizations for their assistance and cooperation during the course of this study:

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PUBLIC AGENCIES

City of Roanoke, Virginia

H. C. Broyles - Director of Public Works

H. S. Zimmerman - Superintendent, Water Pollution Control Plant

Department of City Planning

Roanoke Valley Regional Planning Commission

United States Weather Bureau - Woodrum Field

Roanoke County Public Service Authority

Virginia State Water Control Board

COMMERCIAL FIRMS

James A. Rogers - Penetryn System, Inc.

Technical Consulting Services, Chemists

SECTION 8

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APPENDIX I

FIELD INVESTIGATION

SMOKE TESTING

The nature of this study required as much information as possible concerning the existing condition of the sanitary sewer lines in the three study areas. To achieve this goal, it was necessary to conduct an extensive field investigation.

The City of Roanoke had already begun a program of smoke testing prior to the undertaking of this project. Therefore, the City's smoke testing crew was assigned the task of smoking the sewers in the study areas under the supervision of Hayes, Seay, Mattern and Mattern. Smoke testing was only one of the methods used to establish the condition of the sanitary sewer lines.

The smoke testing crew usually consisted of four men, but varied at times from three to five. Four men constitute an ideal crew because of the various functions required during testing.

The equipment used by the City consisted of a Steco Model No. DA-20 blower, powered by a 3-1/2 hp gasoline engine. The blower had a capacity of 1750 cfm. In conjunction with the blower, smoke bombs as manufactured by the Superior Signal Company were used. The bombs produced about 40,000 cubic feet of smoke and burned for about 3 minutes. The equipment was transported using a City-owned dump truck, but a smaller size such as a pick-up truck would suffice.

When the crew arrived at a section of line requiring smoking, the blower was unloaded and placed alongside an open manhole. The smoke bomb was attached to the blower by a string using a sliding loop around the bomb for easy removal. The bomb was lighted and lowered into the manhole and the blower was started and placed over the manhole opening.

Once the bomb was lit and the blower in operation, it took only a few seconds for smoke to appear at various points. The first place smoke appeared was from vent pipes on the roofs of homes and businesses. If any were connected, smoke would soon appear from downspouts and curb or drop inlets. Smoke also appeared from cracks along walks and curb and gutter.

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In an effort to uncover additional smoking violations, sewer lines were plugged at adjacent manholes upstream and downstream. However, no better results were obtained and the time required was about doubled, so the procedure of plugging the sewer lines was abandoned.

Initially, 3-minute bombs were used. However, 5-minute bombs gave better results as they allowed more time to locate and record the test results.

RECORD OF RESULTS

The results of the investigation were tabulated in a manner describing the type of infraction in the sewer line that would allow storm-surface-runoff to enter directly into the sanitary sewer system. Also, the location of the infraction was noted and the location was recorded on an area map using symbols to depict the particular type.

COSTS

The following is a breakdown of costs involved in the smoke testing portion of the field investigation:

Equipment	Cost
Steco Model No. DS-20 Blower	$220.00
Smoke Bombs, 3-minute	$ 12.00 per dozen

It took approximately one smoke bomb per manhole during the testing program. For 6000 feet of sewer line, there was a manhole about every 250 feet or 40 manholes in the 6000 feet of line. It would take about 40 smoke bombs to smoke this section of line. At $12.00 per dozen this would be approximately $40.00 for smoke bombs.

One crew could test and record the results of about one mile of collector line per day. The cost of such testing averaged about $300 per mile of sewer.

APPENDIX II

HYDROLOGICAL INVESTIGATION

EQUIPMENT

The geographical location of Roanoke made it necessary to locate several rain gauges in the valley to obtain a cross-section of all rainfall events. The equipment selected was one universal recording rain gauge and two non-recording gauges. The recording rain gauge, Figure 28, recorded the rainfall by use of a weighing mechanism which caused a pen to trace, on a chart, changes in a pre-balanced collection system. The daily charts used with the gauge could record up to 6 inches of total rainfall. Each non-recording rain gauge, Figure 29, was a direct reading type as manufactured by Belfort Instrument Company. The measuring tube was 23 inches long, had a capacity of ten inches and measured to the nearest tenth inch of rainfall.

METHODOLOGY

The location of the rainfall gauges was determined by the rainfall pattern to be expected in the Roanoke Valley during the testing period. Rainfalls tend to follow the mountain ridges, especially during the summer months, and it was necessary to obtain the variation in rainfall pattern. To accomplish this end, the recording rain gauge was placed in the Murray Run study area, a non-recording rain gauge was placed in the Trout Run area and in the 24th Street area, and use was made of the recording rain gauge located at the U. S. Weather Bureau at Woodrum Airport north of the City. Data from the gauges were recorded after each rainfall event and tabulated in appropriate order for future use. To expand the rainfall data collected during the events measured, the local climatological data from the U. S. Department of Commerce were obtained as collected by the local U. S. Weather Bureau for the past five years.

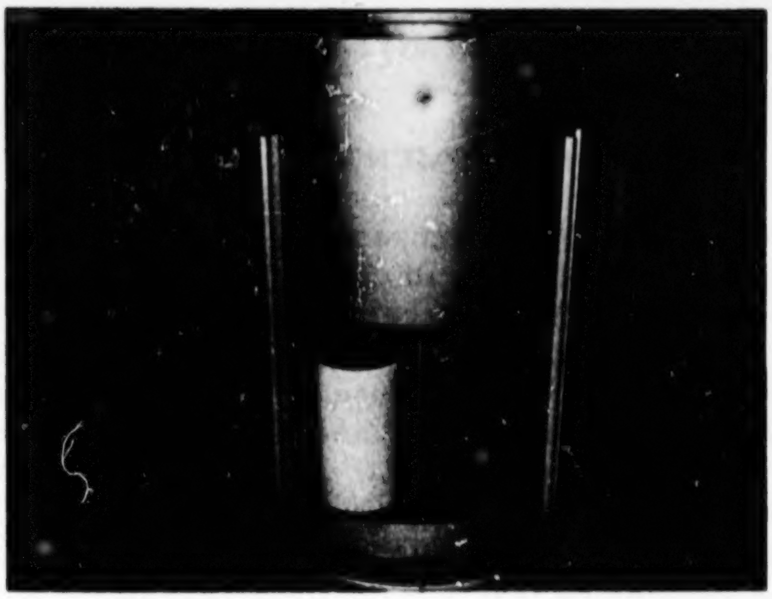

Figure 28. Recording Rain Gauge

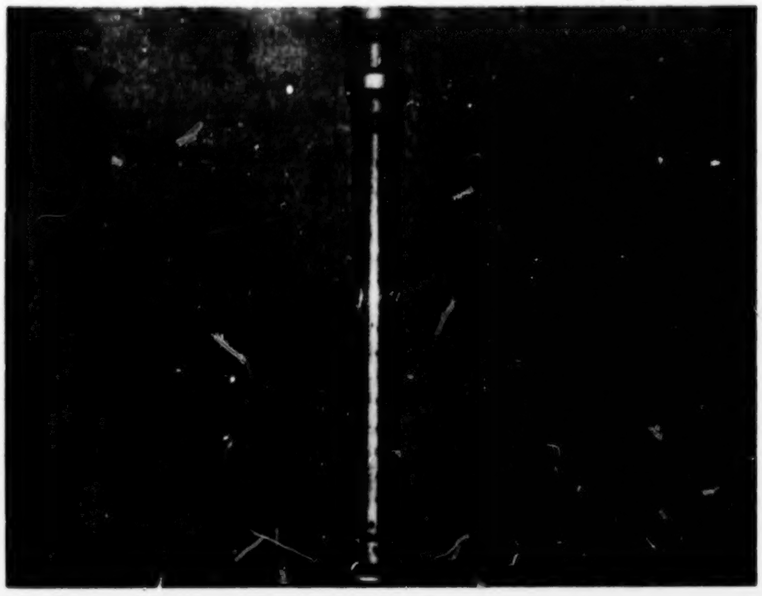

Figure 29. Non-recording Rain Gauge

PROBLEMS

A six month delivery time for new rain gauging equipment was not anticipated. The manufacturers of recording rain gauges are geared for production of the gauges for only several months each year and manufacture only those back ordered. Because of this delay, a recording gauge was furnished by the FWQA; however, it was an old gauge that had been used and declared obsolete by the USGS and had a weekly timing mechanism and 9-inch recording chart. The gauge was recalibrated by the Belfort Instrument Company and equipped with a 24-hour timing mechanism and a 6-inch chart for use on short duration rainfalls. It took approximately eight weeks for delivery of the modified gauge.

The use of the two non-recording rain gauges proved unsatisfactory for other than simply measuring total rainfall. Due to the greater variation in rainfall patterns than expected, recorded intensities could not be satisfactorily correlated with only total rainfall from the non-recording gauges.

COSTS

Following is a breakdown of the approximate equipment costs involving the hydrological investigation:

Repair old recording rain gauge	$27.00
Chart paper	5.00
Non-recording rain gauge	56.00
	$88.00
OR	
New recording rain gauge	$325.00
Non-recording rain gauge	56.00
	$381.00

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APPENDIX III

GAUGING OF STREAMS AND SEWERS

EQUIPMENT

The equipment used to record the flow in the streams and sanitary sewers in the three study areas consisted of six continuous water level recorders manufactured by the Instruments Corporation, now a part of Belfort Instrument Company. Also, one pressure type recorder manufactured by the Bristol Company of Waterbury, Connecticut, was used. The operation of each continous water level recorder consisted of a time element and a stage element. The time element is driven by a clock weight and regulated to a constant speed by a clock escapement. Power is transmitted through a driving roll, which unwinds the paper from a supply roll and feeds it onto a take-up roll at the rear of the instrument case, as a finished record. The stage element is activated by a float at water level which is connected by a flexible stainless steel perforated tape and suitable counterweight to a spined float wheel. Any movement of the float records in a direct ratio of inches of chart to inches of stage. The rise and fall of the water is plotted as an ordinate against time as an abscissa. The water level recorders and pressure gauge are shown by Figures 30 and 31. The Bristol pressure gauge operates by measuring the pressure due to the depth of liquid by bubbling a gas such as CO_2 through a long tube inserted into the liquid. The gauge releases the gas at a constant pressure and as the depth of the liquid changes the pressure differential is recorded on a circular chart in inches of depth.

METHODOLOGY

All gauges were located as near as possible to the lower end of the respective study areas. In the Murray Run study area, the site for the stream gauge was based upon as uniform flow conditions as could be found in the channel. A 24-inch corrugated standpipe was used as a stilling well with a continuous level recorder situated on top of the pipe as shown by Figure 6. Flows were calculated based upon the hydraulic characteristics of the stream channel. It was impossible to find an existing manhole in the Murray Run sanitary sewer that could be used to measure the depth of flow, because of non-uniform flow conditions in the manholes. A specially designed manhole was constructed over a section of the sewer having uniform flow, as shown by Figure 7. The

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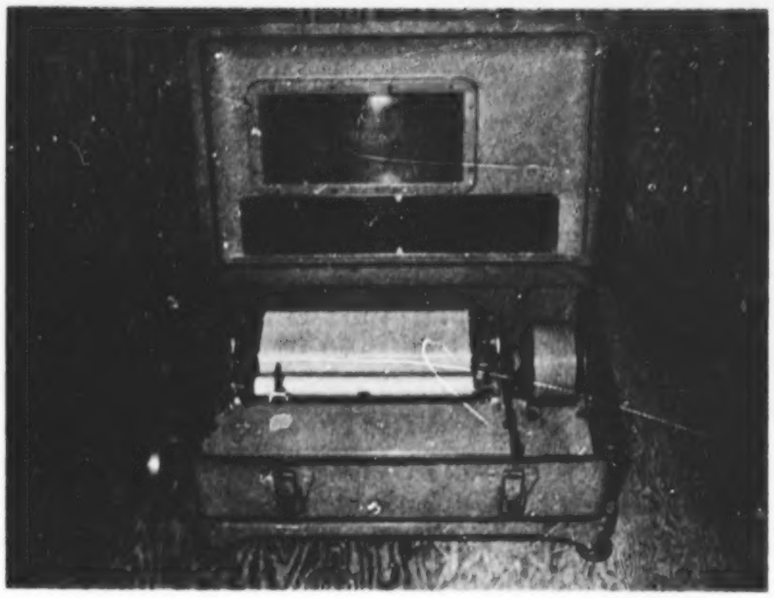


Figure 30. Water Level Recorder

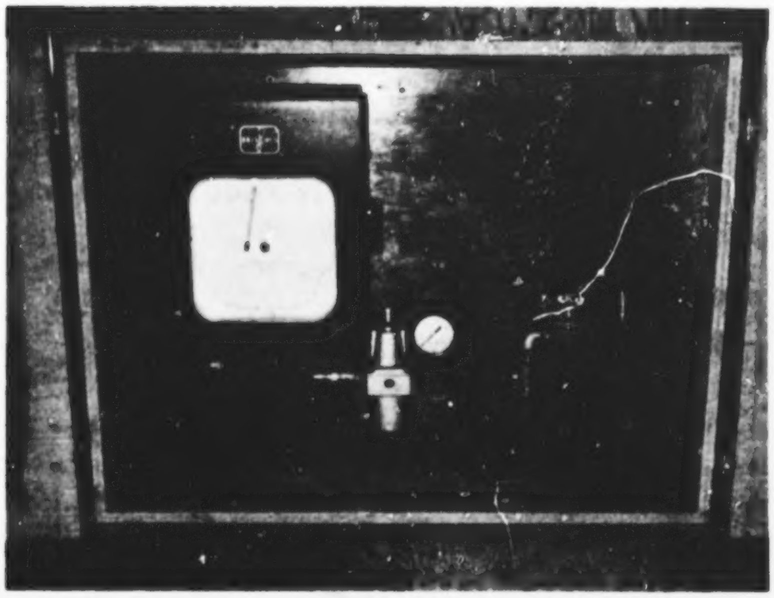


Figure 31. Bristol Pressure Gauge

hydraulic elements of the lower half of the sanitary sewer were used to determine the dry weather flow. The root masses in the upper half of the sewer made it impossible to establish the hydraulic characteristics when the line was flowing more than one half full. Increases in flow due to infiltration caused the sewer to surcharge and overflow at manholes. Therefore, in order to obtain a more accurate reading of overflows, a weir was installed in the side of the manhole wall. The normal dry weather flow was allowed to continue through the line, but when the manhole surcharged during a rainfall event, the overflow passed over the weir into the Murray Run stream, thus giving an accurate measure of overflow.

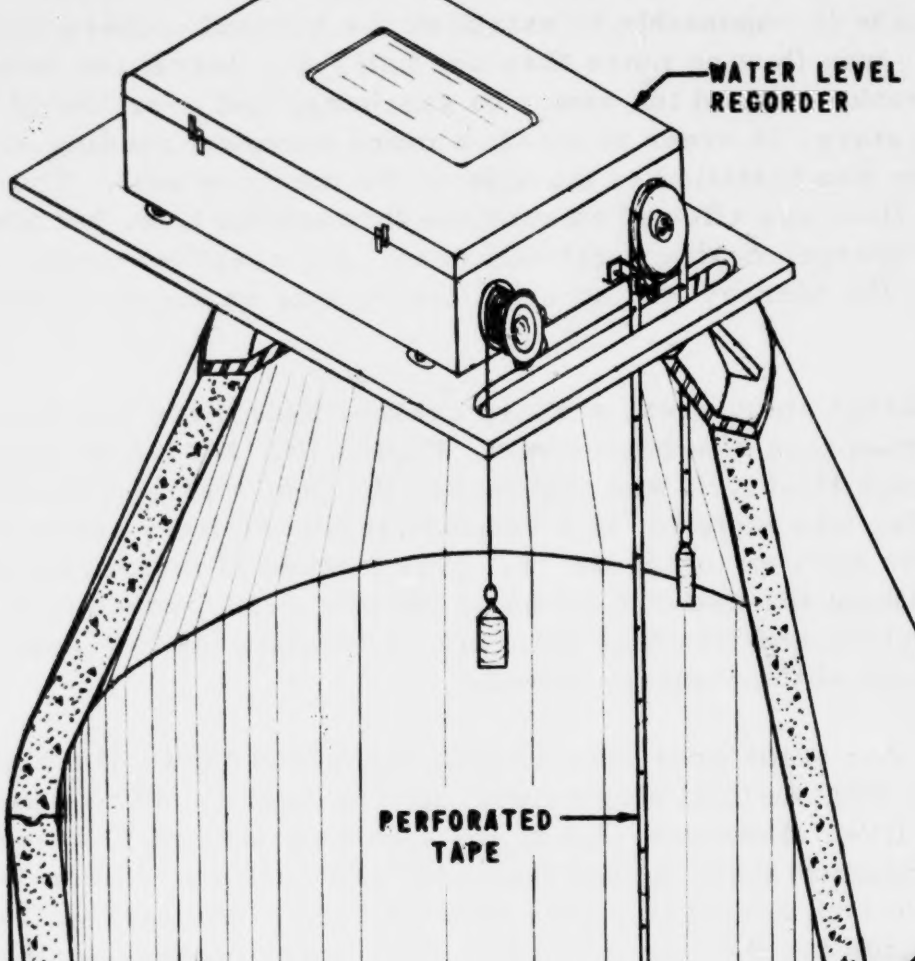
In the 24th Street study area, a sharp crested weir plate was installed on the upstream face of a box culvert, Figure 10. A 24-inch diameter corrugated pipe float well was fastened to the head wall. A continuous stage recorder was installed in a manhole in the sanitary sewer using an installation similar to Figure 32. This method of measuring the in-line flow, without the use of a flume or stilling well, proved to be the most satisfactory and flow was determined by using the hydraulic characteristics of the sanitary sewer.

In the Trout Run study area, the stream channel consists of a curved concrete bed with vertical stone sides, giving ideal conditions for determining flow. However, due to the small quantity of flow and insufficient depth of flow, a concrete weir was constructed across the channel. A 9-inch corrugated pipe was fastened to the side wall to serve as a guide for the float from the water level recorder and also provide a stilling well for accurate measurement of flow in the stream. Figure 8 shows the installation in Trout Run stream. The initial gauge location in the sanitary sewer was unsatisfactory as the sewer surcharged during each rainfall event. Other locations were unsuitable due to physical obstacles.

The gauge was eventually relocated to a manhole in the center of a street and permanent barricades were maintained. The installation was similar to Figure 32, and proved quite satisfactory for a wide range of flows.

A water level recorder was installed at the overflow structure at the Water Pollution Control Plant, in order to determine the quantity of sewage bypassed at the plant during rainfall events. Due to a limited number of recorders, the recorder in the 24th Street stream was relocated to the plant.

FIGURE 32 WATER LEVEL RECORDER INSTALLATION IN SANITARY SEWER MANHOLE


WATER LEVEL RECORDER
PERFORATED TAPE
FLOAT ANCHOR ARM
FLOAT

The stage recorders were left running continuously and had to be checked about three times a week to wind the clock. At this time, the chart was removed, dated and appropriately marked for future use. The Bristol pressure gauge was put in operation only during rainfall events because the bubbler pipe collected debris and required frequent cleaning, at least hourly. Because of the maintenance problem the bubbler type gauge was unsatisfactory when installed in the direct stream flow and the gauge was replaced with a continuous water level recorder.

PROBLEMS

The problems encountered during the study relating to stream and sewer gauging were limited to the equipment initially and minor problems later during gauging. The six continuous water level recorders were on loan from the FWQA. The recorders had previously been used by the USGS for gauging rivers and were not geared for the small measurements encountered when gauging small streams and sewer flows. It was further learned that the instruments were obsolete and had been replaced by the USGS with a new model of a similar machine. The only parts readily available were the recording pens and the chart paper which were the only items interchangeable with the updated machine. In order to adapt the machines for use in streams and sewers, it was necessary to change the gear ratio on the time element to provide maximum paper travel of 9.6 inches per day in lieu of the existing 2.4 inches per day. Copies were obtained from Belfort Instrument Company of detail drawings of the desired gears. New gears were made locally and installed in the machines. After this, the water level recorders worked satisfactorily throughout the remainder of the program. However, the gauging program was delayed for about 8 weeks.

COSTS

Below is a breakdown of costs required to put the water level recorders in satisfactory operating condition so that they could be used in the gauging program.

Equipment	Cost
12 Gears	$200
12 Rolls chart paper	60
6 Floats	135
6 Float counterweights	19
6 Clock weights	61
Ink, pens, float tape, etc.	73
	$548

The cost for six new water level recorders would have been an additional $1700 or a total of $2248 for gauging equipment. The Bristol pressure gauge cost about $800, installed and ready for use.

The approximate costs for construction of the weirs and manhole are as follows:

Location	Construction	Cost
Trout Run	Weir in stream	$1140
24th Street	Weir in stream	$ 900
Murray Run	Manhole	$1240

APPENDIX IV

WATER QUALITY SAMPLING AND TESTING

EQUIPMENT

The equipment used to obtain samples from the streams and sanitary sewers in the three study areas consisted of two Serco samplers for automatic sampling.

The Serco automatic sampler, Figure 33, works on a vaccuum principle. The sampler has 24 bottles in which to collect samples. The sample bottles are all evacuated through the plastic sampling lines and sampling head by use of a vacuum pump. A vacuum of about 26 inches of mercury can usually be obtained depending on the elevation above sea level. After evacuation, each bottle is sealed off by means of an individual switch. The spring driven clock rotates a tripper arm releasing the individual switches thus drawing a sample into the bottle.

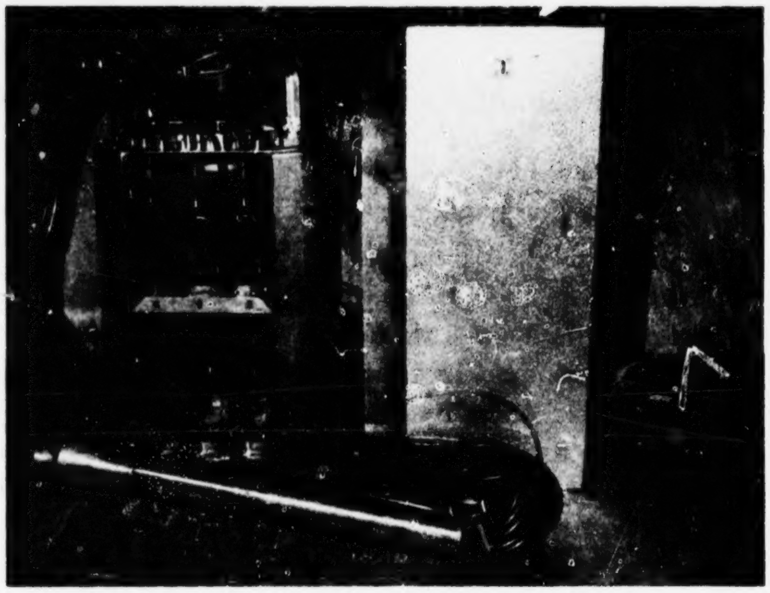


Figure 33. Serco Automatic Sampler

Many accessories are available for the samplers such as:

1. Gears or clocks to vary the sampling interval from 5 minutes to 8 hours.
2. Varying lengths of plastic sampler lines for lifts from 3 feet to 13 feet.
3. Vacuum pump.
4. Electric timers.
5. Mechanical refrigeration.
6. Remote starting switch to start the sampling cycle.

The accessories utilized in this study included the following:

1. Two clocks, one timed to collect samples every hour and one to collect samples every fifteen minutes.
2. Length of sampling hose for 8 feet of lift.
3. Vacuum pump.
4. Remote starting mechanism to start the sampling cycle.

METHODOLOGY

The samples were taken as close to the point of gauging as possible. Funds were available for only two automatic samplers. These automatic samplers were used as a pair in one study area, obtaining samples from the stream and sanitary sewer simultaneously during a rainfall event. During the same event, the other two study areas were manually sampled at various time intervals. The automatic samplers were moved from time to time to the other study areas.

Sampling at the Water Pollution Control Plant was done manually with samples taken from the comminutor room.

After obtaining the samples, they were iced down and transported to the laboratory for analysis. Tables 51 through 56 give the sanitary sewer and stream characteristics in tabular form.

PROBLEMS

The problems encountered during sampling primarily involved the equipment. The automatic samplers worked rather well except that some precautions had to be taken. In the streams, the nozzle could not be resting on the bottom or sand and grit would be drawn into the sample bottle. Rags from the sanitary sewers would block several of the tube openings during a 24-hour sampling program. Occasionally a clock would stop and a complete rainfall would be missed. The automatic starting devices proved to be inadequate; therefore, the samplers had to be started manually at the beginning of each rainfall, which proved to be time consuming.

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APPENDIX V

COMPUTER PROGRAM

PROGRAM ABSTRACT

The purpose of this program is to determine the locations and potential rates of overflows from sanitary sewers due to infiltration of surface water into the sewers during rainfall.

The necessary field data required for input include the length of collector sewers contributing to flow in the sewer to be analyzed and the hydraulic characteristics (length, slope and diameter) of each line in the sewer to be analyzed.

Additional input data required include the characteristics (average intensity and duration) of the design rainfall event, the dry weather flow (including normal ground water infiltration) of the sewer to be analyzed and an estimate of the BOD concentration in the sewer during rainfall. (Data provided by the study contained herein will be a guide to determining the BOD.) Up to 10 intensity/duration characteristics may be printed in one pass.

The program assumes that all dry weather flow and surface water infiltration are uniformly distributed throughout the sewer and contributing collectors, and that a sewer has a potential to overflow when flow exceeds the capacity of the pipe just flowing full, as determined by the Manning Formula.

The resulting output is a tabulation of each line, beginning at the upstream end and showing manhole number (line designation), capacity, dry weather flow, wet weather flow, rate of potential overflow, volume of potential overflow and pounds of BOD overflowing to a surface water to cause stream pollution, all due to surface water infiltration caused by the design rainfall event.

Totals for the rates and volumes of potential overflow and pounds of BOD for the entire sewer are printed at the end of the tabulation.

The printed output can be analyzed for potential overflow in the sewer and corrective measures taken.

Reruns should indicate the effects of the design changes and any further changes required to meet the design rainfall event.

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OPERATING INSTRUCTIONS

IBM 1130 System

SWINF (Surface Water Infiltration)

No switches tested

Card Order:

1. **// XEQ SWINF**
2. **Intensity cards (2 required). Zeroes should be punched in unused fields.**
3. **Job title card (1 required).**
4. **Job dry weather flow, BOD, infiltration multiplier.**
5. **Manhole deck (160 maximum). Manhole numbers are input beginning at lower end of system being analyzed.**
6. **Blank card (1 required) to signify end of manhole deck.**
7. **Terminate card (1 required). *punched in card column 80.**

   Note: Repeat 3-6 for stacked jobs using same intensity comparisons. To stack jobs having a new set of intensity cards, insert a blank card preceding the new intensity cards. This card is in addition to the blank which signals the end of the last manhole deck of the previous job. Repeat 3-6 as required.

Files: Temporary - 160 records, 10 words each.

```
// JOB
// FOR
*ONE WORD INTEGERS
*LIST SOURCE PROGRAM
*IOCS(CARD,1132PRINTER,DISK)
*NAME SWINF
*TRANSFER TRACE
*ARITHMETIC TRACE
**    PROGRAM TO DETERMINE LOCATIONS AND RATES OF POTENTIAL SEWER
**    OVERFLOWS DUE TO SURFACE WATER INFILTRATION.
      DEFINE FILE 1(160,10,U,N1)
      DIMENSION IO(80),XINTS(10),DUR(10)
    7 FORMAT(3X,I2,9X,F7.4,3F19.4,F15.4,I13)
  100 READ(2,200)(XINTS(I),DUR(I),I=1,10)
  200 FORMAT(10F6.2)
  101 I=1
C     READ AND PRINT JOB TITLE
      READ(2,1)IO
    1 FORMAT(80A1)
      IF(IO(1)-23616) 102,999,102
  102 IF(IO(1)-16448) 103,100,103
  103 WRITE(3,2)IO
    2 FORMAT(1H1,80A1,/)
      READ(2,5)DWFDA,BOD,XMUL
    5 FORMAT(F10.2,F8.2,F4.2)
      WRITE(3,9)XINTS(I),DUR(I)
    9 FORMAT(' DESIGN RAINFALL - ',F5.2,' IN/HR AVERAGE INTENSITY',
     1F13.2,' HOURS DURATION',/)
C     WRITE PAGE HEADINGS
      WRITE(3,3)
    3 FORMAT(' UPSTREAM    LINE CAPACITY    DRY WEATHER FLOW    WET WEAT
     1HER FLOW     POTENTIAL SEWAGE OVERFLOWS    TOTAL BOD')
      WRITE(3,4)
    4 FORMAT('  MH NO',10X,'MGD',15X,'MGD',17X,'MGD',12X,'RATE - MGD',
     15X,'VOLUME - MG',7X,'LBS',/)
C     READ ALL INPUT CARDS FOR FILE 1. MANHOLE NO.,DIAMETER,COLLECTOR
C     LENGTHS,LINE LENGTH,SLOPE. BLANK CARD TERMINATES.
      N1=1
   20 READ(2,6)MHNO,DIAM,COLL,XLINE,SLOPE
```

```
    6 FORMAT(I3,F3.0,2F6.0,F8.5)
      IF(MHNO)21,300,21
  300 TOTMH=N1-1
      GO TO 24
   21 DIAM=DIAM/12.
      WRITE(1'N1)MHNO,DIAM,COLL,XLINE,SLOPE
      IF(N1-2)23,22,23
C     COMPUTE THE TOTAL LENGTH OF COLLECTORS AND INTERCEPTORS
C     CONTRIBUTING TO THE FIRST LINE IN THE SEWER.
   22 TOLIN=COLL
      GO TO 20
   23 TOLIN=TOLIN+XLINE+COLL
      GO TO 20
C     INFILTRATION RATE FOR THE DESIGN RAINFALL EVENT FROM EQUATION
C     DEVELOPED BY ROANOKE POLLUTION STUDY.
   24 XINFL=(1.98438*XINTS(I)-0.0870)/10000.*XMUL
C     INITIALIZE TOTALS
C     KTREM IS NO. LINES PER PAGE
      KTREM=50
C     TRPOF IS TOTAL RATE OF POTENTIAL OVERFLOW
      TRPOF=0.
C     TPOF IS TOTAL VOLUME OF THE POTENTIAL OVERFLOW
      TPOF=0.
C     LBBOD IS TOTAL LBS. OF B.O.D. ACTUALLY REACHING AN ADJOINING STR.
      LBBOD=0.
C     DWFPF IS SYSTEM DRY WEATHER FLOW PER FOOT
      DWFPF=DWFDA/TOLIN
C     BEGIN INVESTIGATION AT UPSTREAM END
      NREC=TOTMH
      READ(1'NREC)MHNO,DIAM,COLL,XLINE,SLOPE
      TLINE=COLL
C     DWF IS DRY WEATHER FLOW THIS LINE
   40 DWF=DWFPF*TLINE
C     FLOW DUE TO GROUND WATER INFILTRATION
      FLOW=XINFL*TLINE
      IF(SLOPE)28,28,29
C     QFULL IS CAPACITY THIS LINE FLOWING FULL USING MANNING EQUATION
```

```
C     ROUGHNESS COEFFICIENT OF .014
   28 QFULL=0.
      GO TO 30
   29 QFULL=(83.3646*(1./4.**(2./3.))*DIAM**(8./3.)*SLOPE**.5)*.646
C     RPOF IS RATE OF POTENTIAL OVERFLOW THIS LINE
   30 RPOF=DWF+FLOW-TRPOF-QFULL
      IF(RPOF)104,104,105
  104 WWF=DWF+FLOW-TRPOF
      LBOD=0
      POF=0.
      RPOF=0.
      GO TO 149
  105 WWF=QFULL
C     POF IS VOLUME OF POTENTIAL OVERFLOW THIS LINE
   31 POF=RPOF*(DUR(I)/24.)
C     LBOD IS TOTAL POUNDS B.O.D. THIS LINE ACTUALLY REACHING ADJ. STR.
      LBOD=8.34*POF*BOD+.5
C     KEEP RUNNING TOTALS
      TRPOF=TRPOF+RPOF
      TPOF=TPOF+POF
      LBBOD=LBBOD+LBOD
C     ROOM TO PRINT &
  149 IF(KTREM)32,32,33
   32 WRITE(3,2)
      WRITE(3,3)
      WRITE(3,4)
      KTREM=50
   33 WRITE(3,7)MHNO,QFULL,DWF,WWF,RPOF,POF,LBOD
      KTREM=KTREM-1
   35 TLINE=TLINE+XLINE
   25 NREC=NREC-1
      IF(NREC)34,34,26
   26 READ(1'NREC)MHNO,DIAM,COLL,XLINE,SLOPE
      TLINE=TLINE+COLL
      GO TO 40
C     JOB TOTALS ROUTINE
   34 WRITE(3,8)TRPOF,TPOF,LBBOD
```

```
 OVERFLOWS DUE TO SURFACE WATER INFILTRATION.                          PAGE 04

   8 FORMAT(/,40X,'INTERCEPTOR TOTALS =',3X,2F15.4,I13)
     IF(I-10)201,101,101
 201 IF(XINTS(I+1))101,101,202
 202 I=I+1
     WRITE(3,2)IO
     WRITE(3,9)XINTS(I),DUR(I)
     WRITE(3,3)
     WRITE(3,4)
     GO TO 24
 999 CALL EXIT
     END

UNREFERENCED STATEMENTS
 31      35      25

FEATURES SUPPORTED
 TRANSFER TRACE
 ARITHMETIC TRACE
 ONE WORD INTEGERS
 IOCS

CORE REQUIREMENTS FOR SWINF
 COMMON      0  VARIABLES    182  PROGRAM    762

END OF COMPILATION
```

APPENDIX VI

RAINFALL INTENSITY AND RATE OF DISCHARGE FOR THE THREE STUDY AREAS

FIGURES 34 THROUGH 101

FIGURE 34 RAINFALL INTENSITY AND RATE OF DISCHARGE MURRAY RUN STREAM

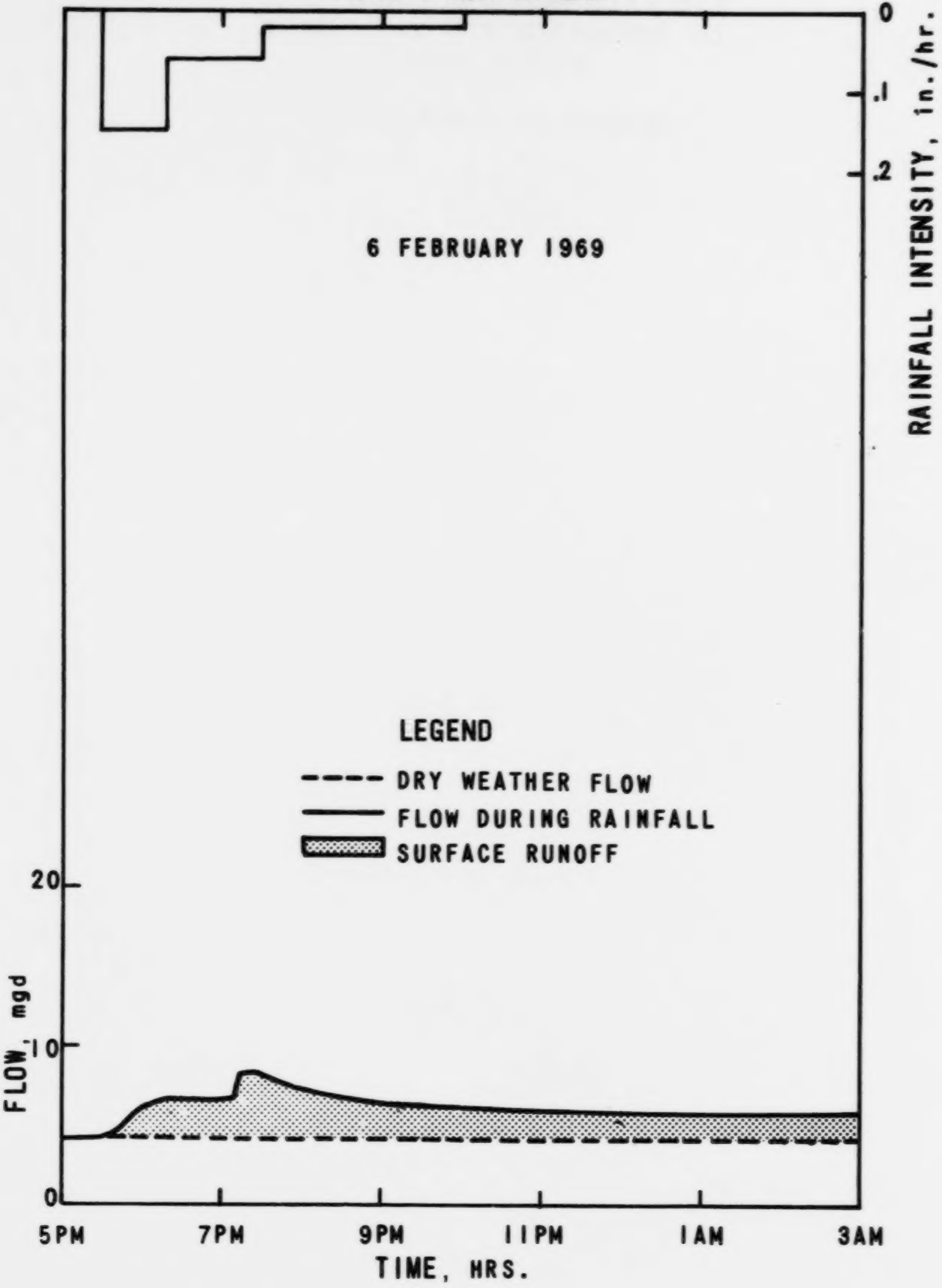


FIGURE 35 RAINFALL INTENSITY AND RATE OF DISCHARGE MURRAY RUN STREAM

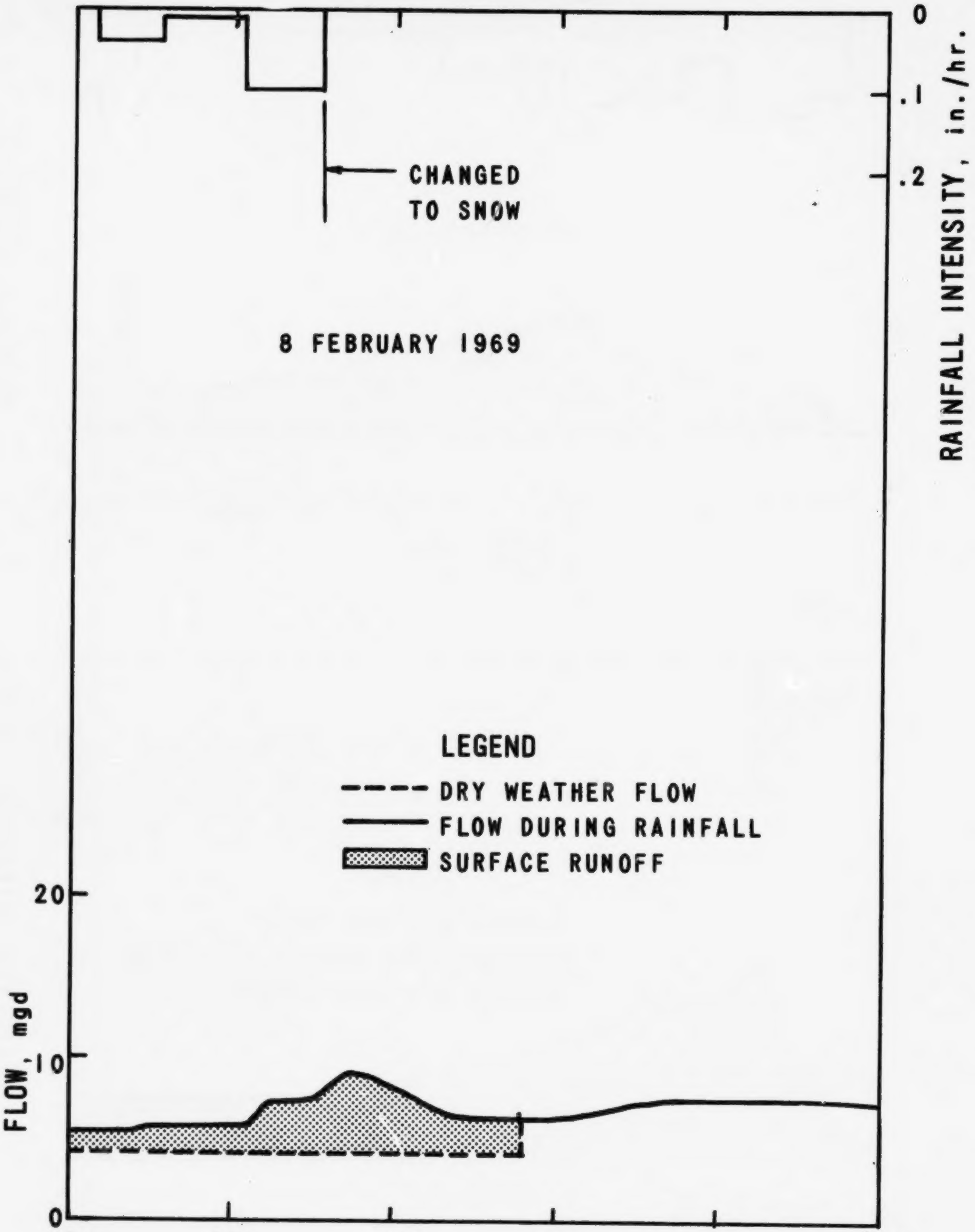


FIGURE 36 RAINFALL INTENSITY AND RATE OF DISCHARGE MURRAY RUN STREAM

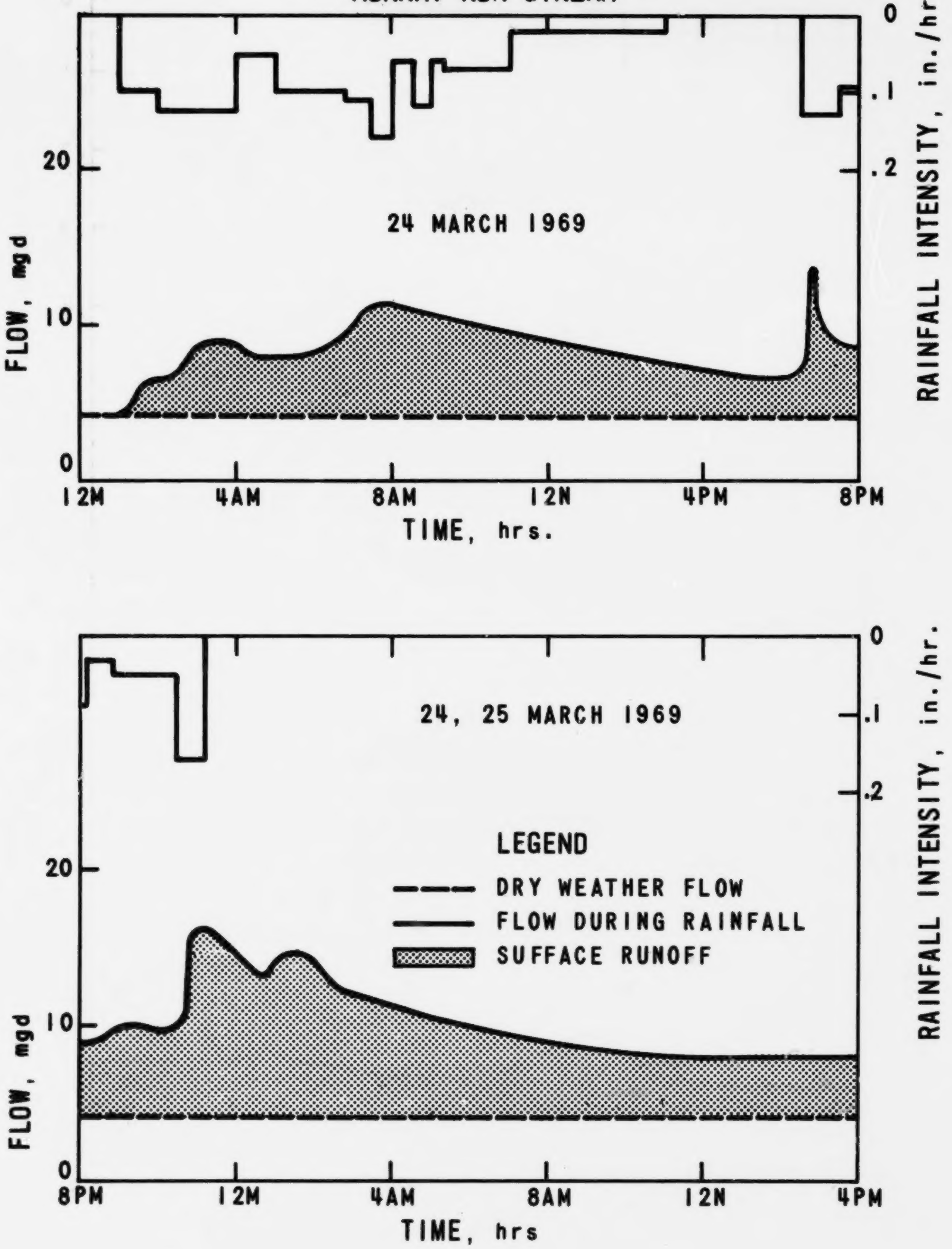


FIGURE 37 RAINFALL INTENSITY AND RATE OF DISCHARGE
MURRAY RUN STREAM

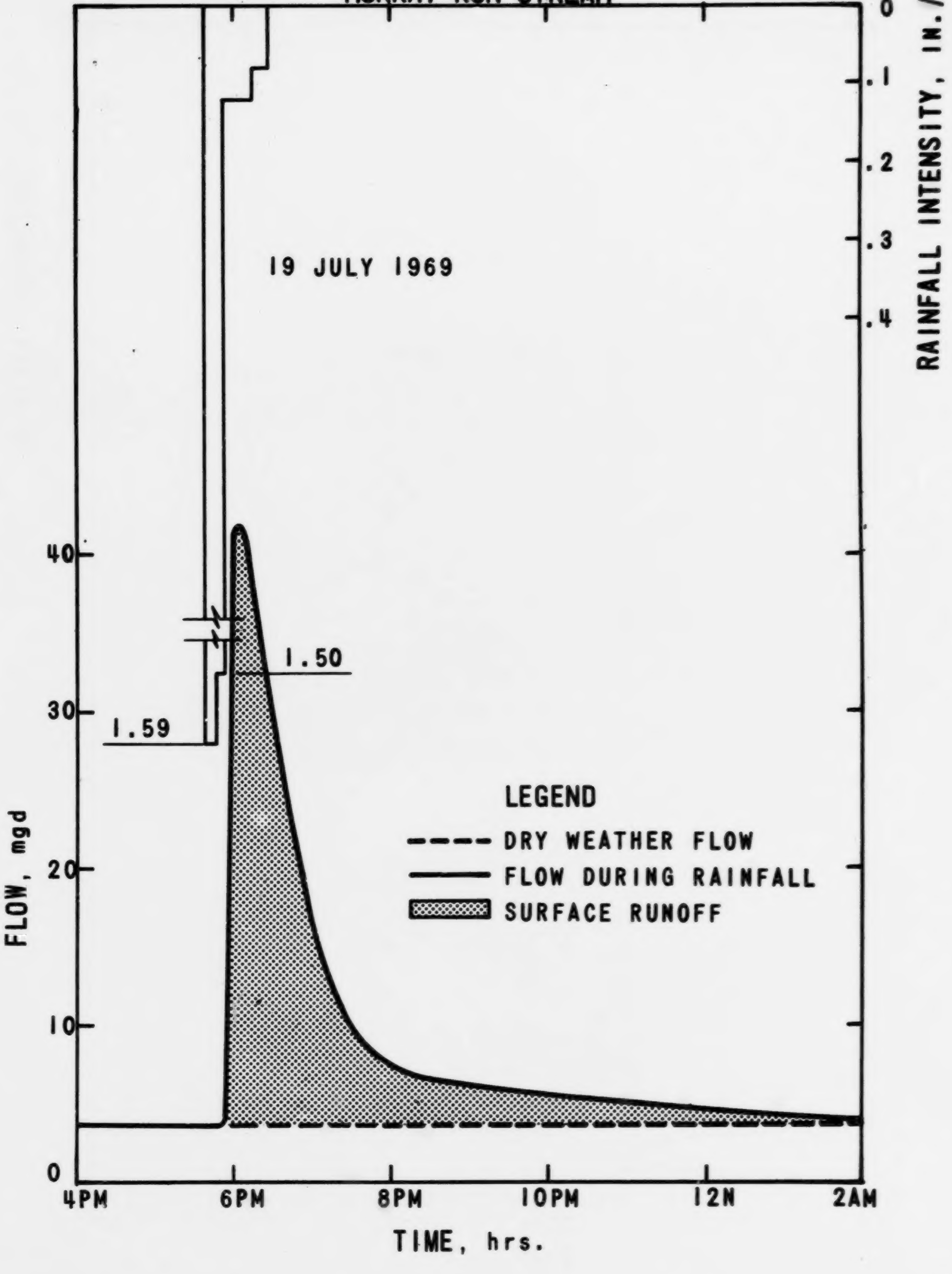


FIGURE 38 RAINFALL INTENSITY AND RATE OF DISCHARGE
MURRAY RUN STREAM

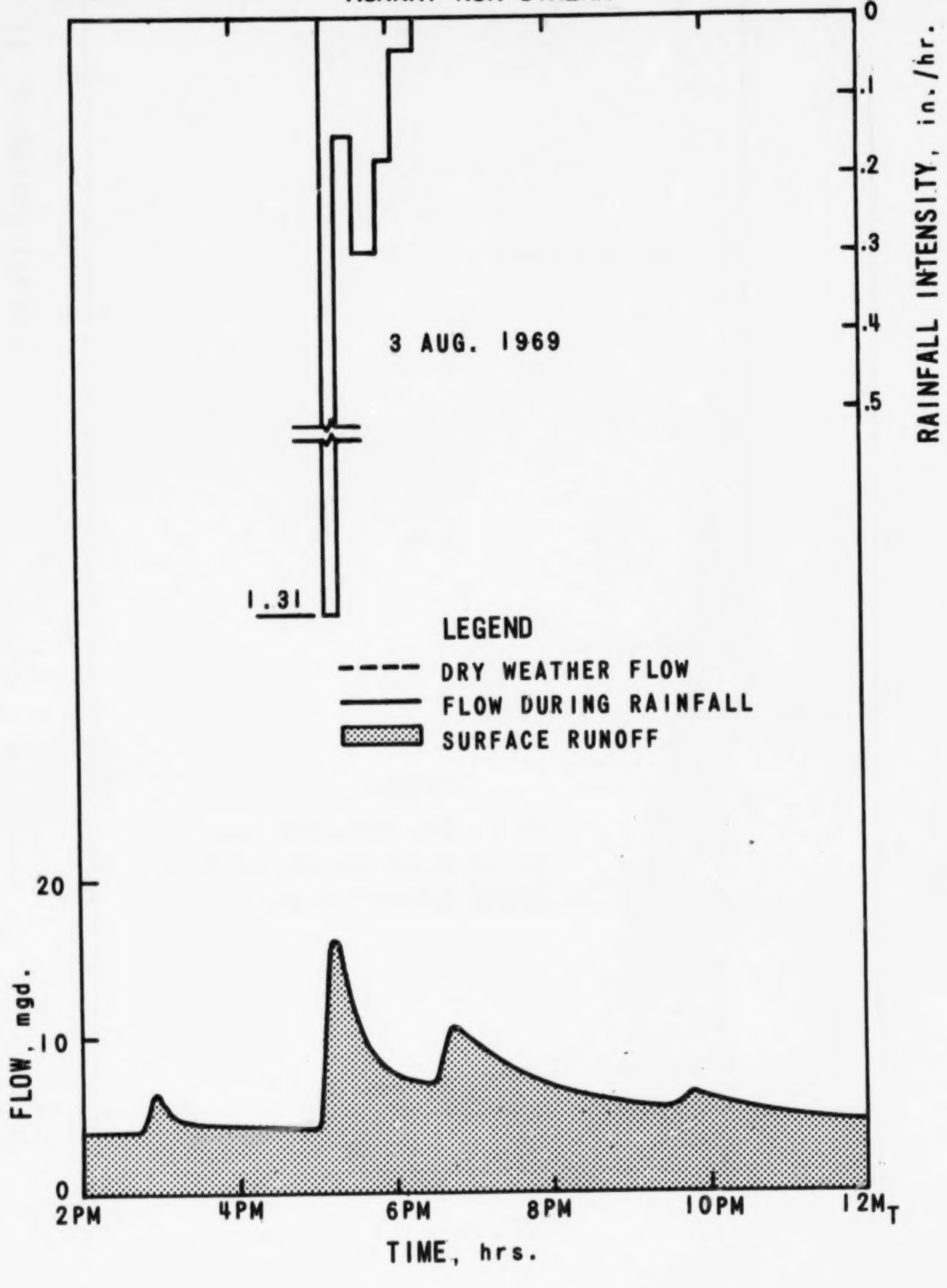


FIGURE 39 RAINFALL INTENSITY AND RATE OF DISCHARGE
TROUT RUN STREAM

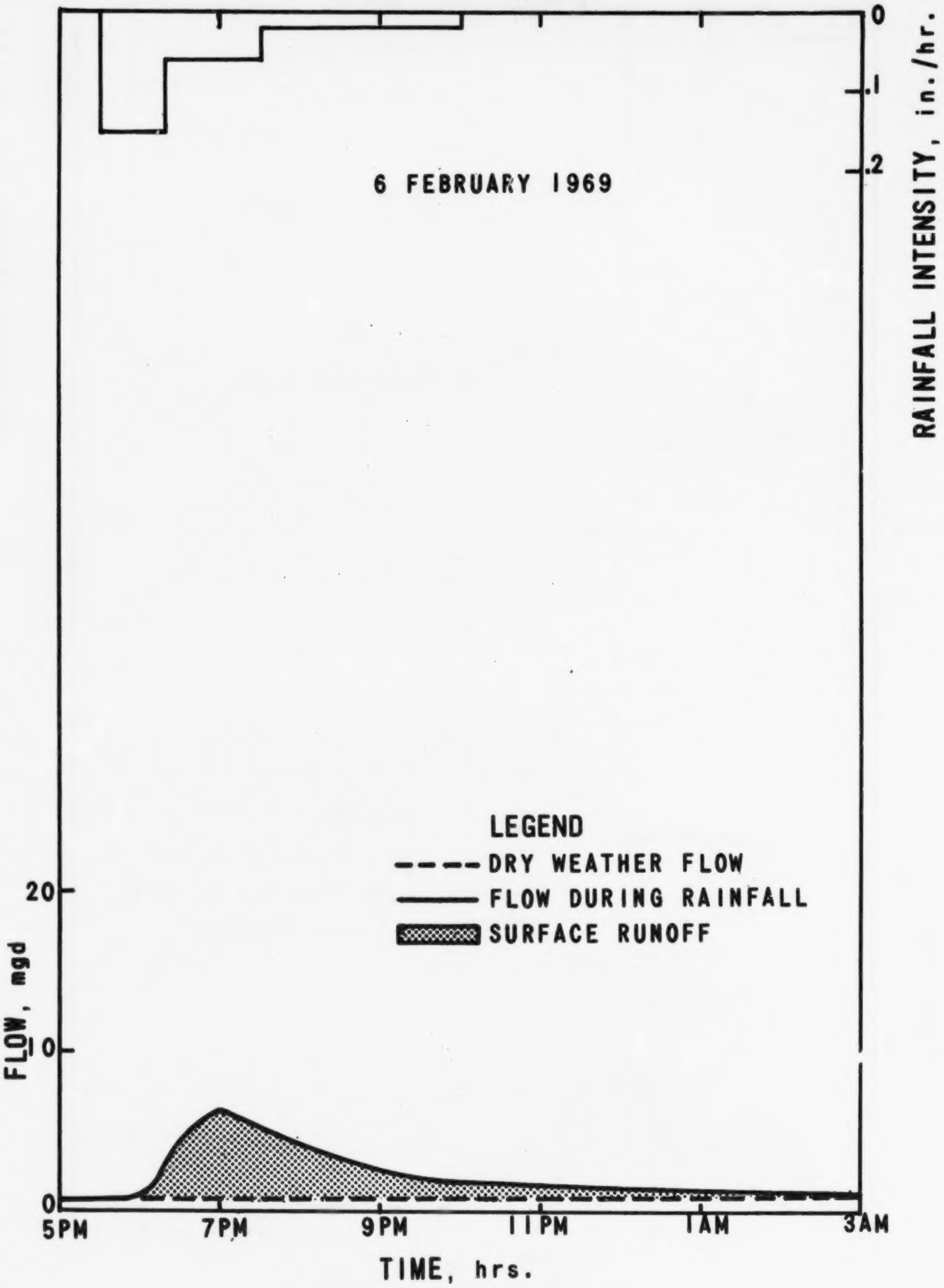


FIGURE 40 RAINFALL INTENSITY AND RATE OF DISCHARGE
TROUT RUN STREAM

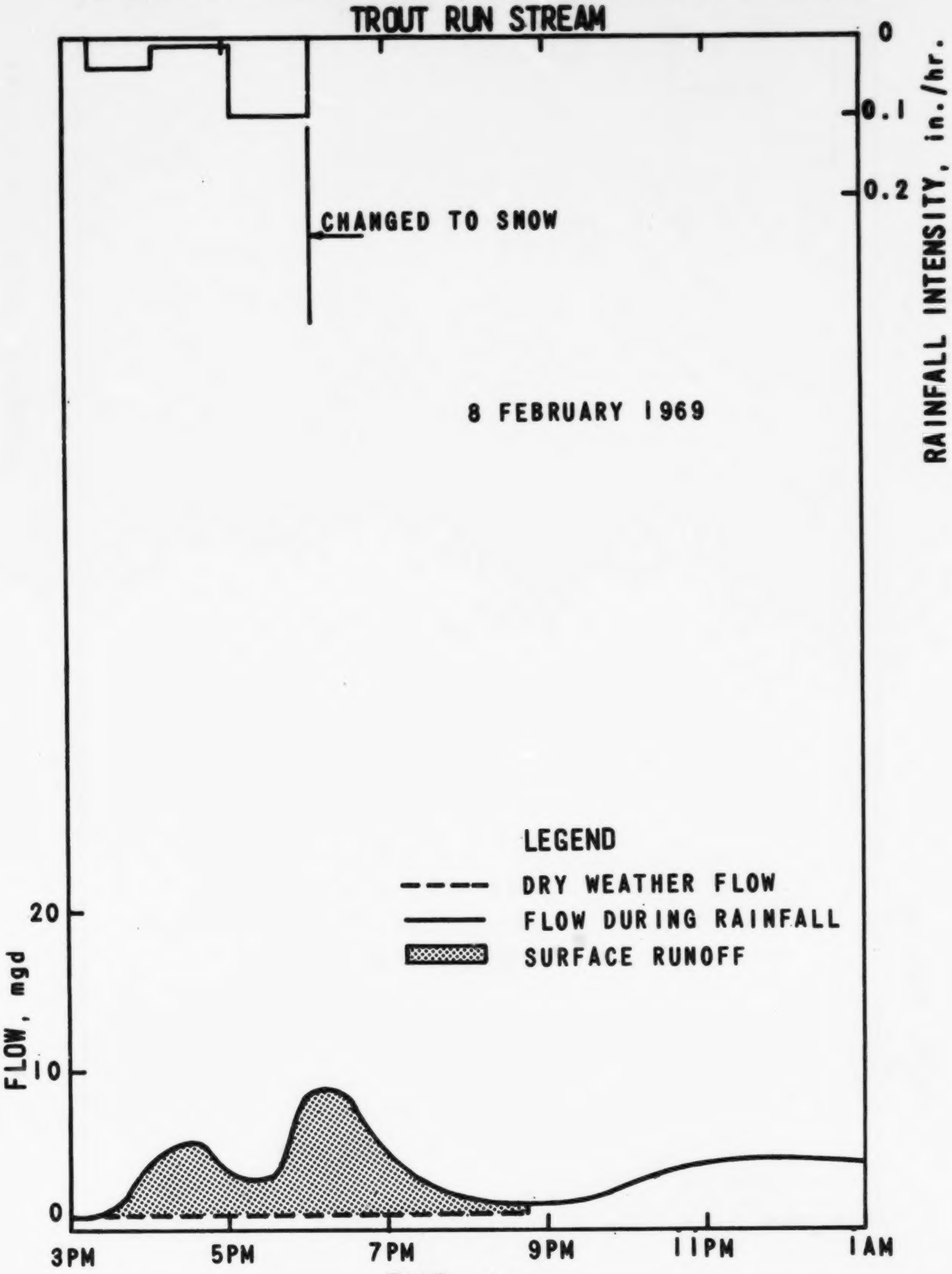


FIGURE 41 RAINFALL INTENSITY AND RATE OF DISCHARGE
TROUT RUN STREAM

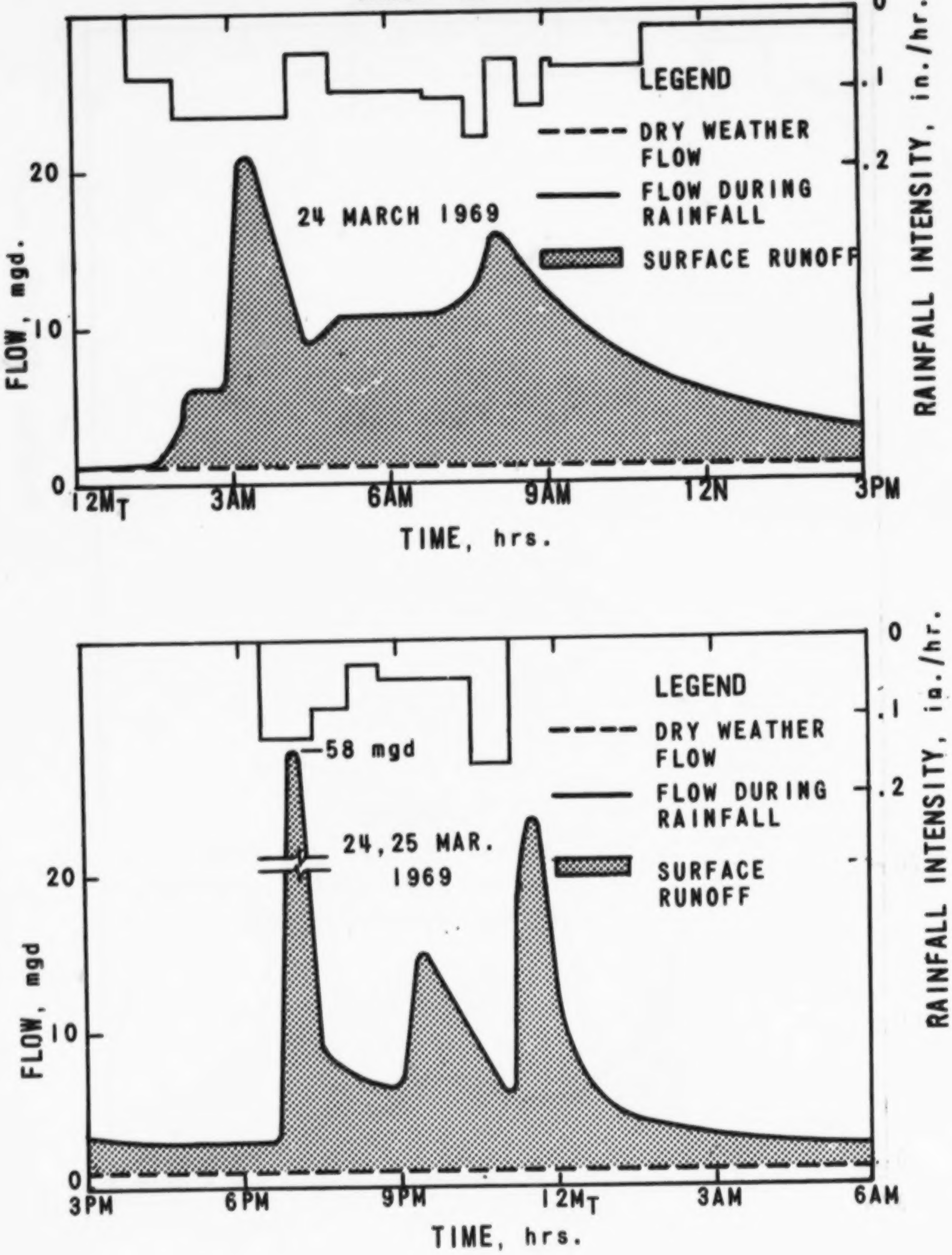


FIGURE 42 RAINFALL INTENSITY AND RATE OF DISCHARGE
TROUT RUN STREAM

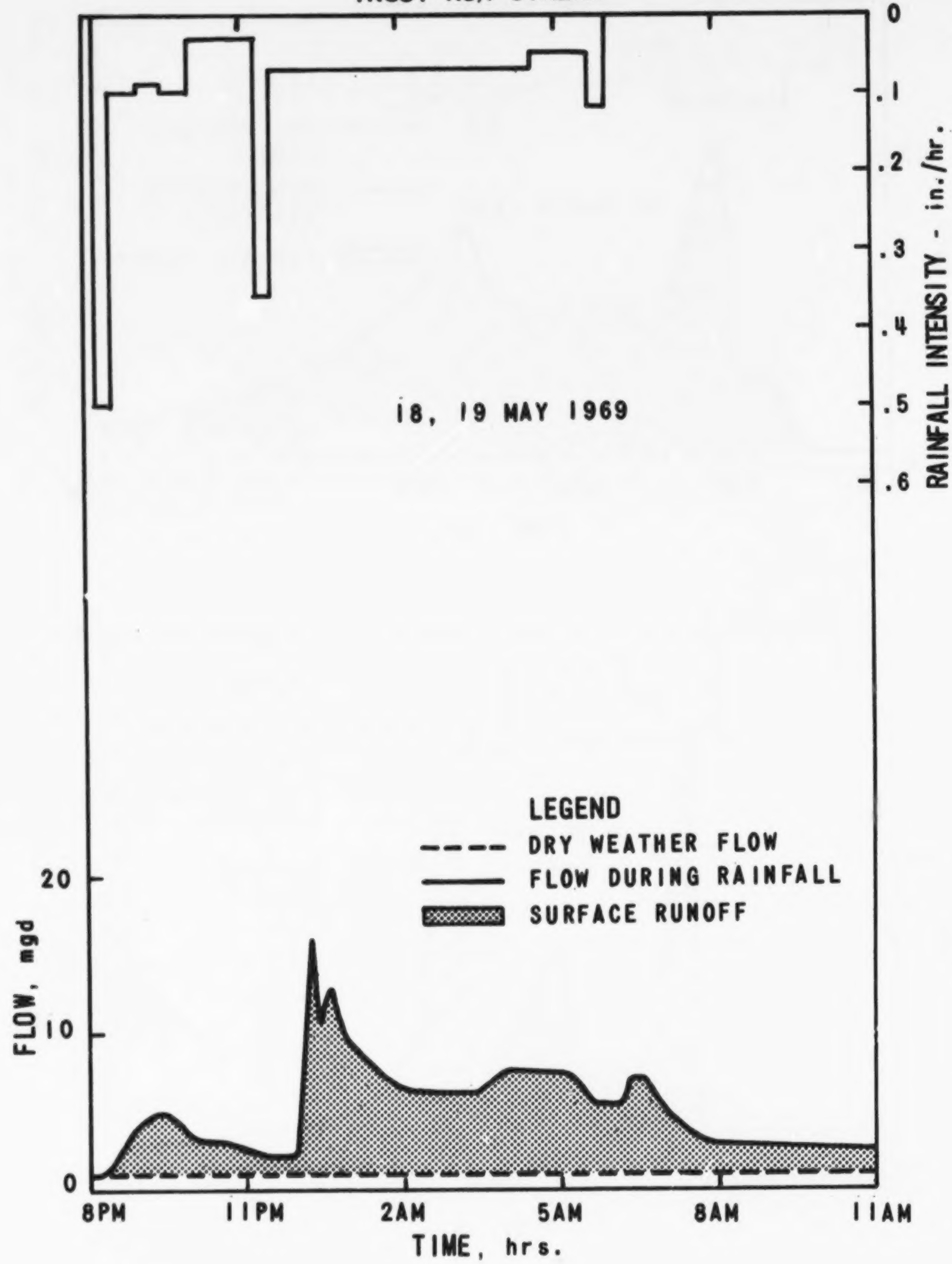


FIGURE 43 RAINFALL INTENSITY AND RATE OF DISCHARGE
TROUT RUN STREAM

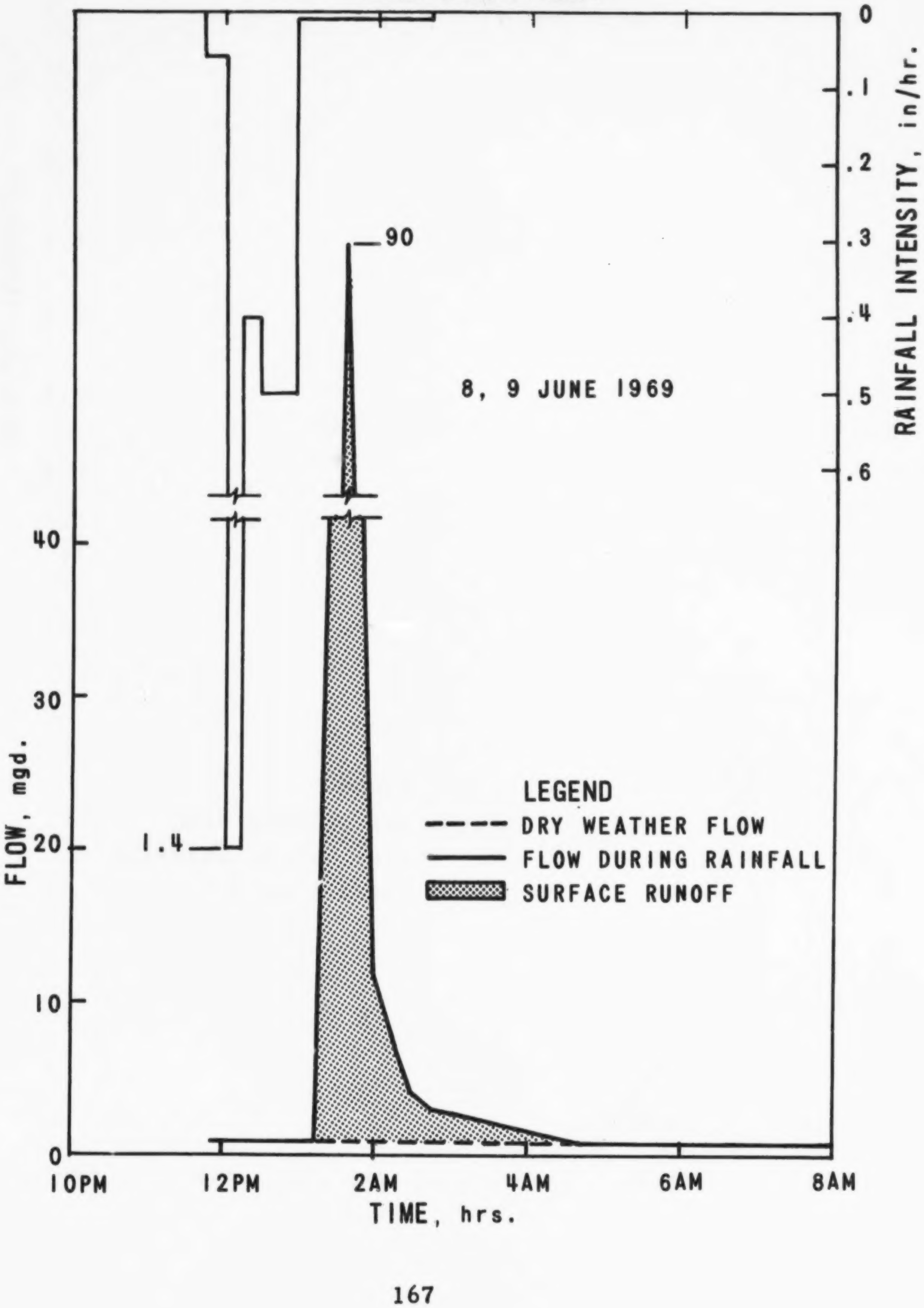


FIGURE 44 RAINFALL INTENSITY AND RATE OF DISCHARGE TROUT RUN STREAM

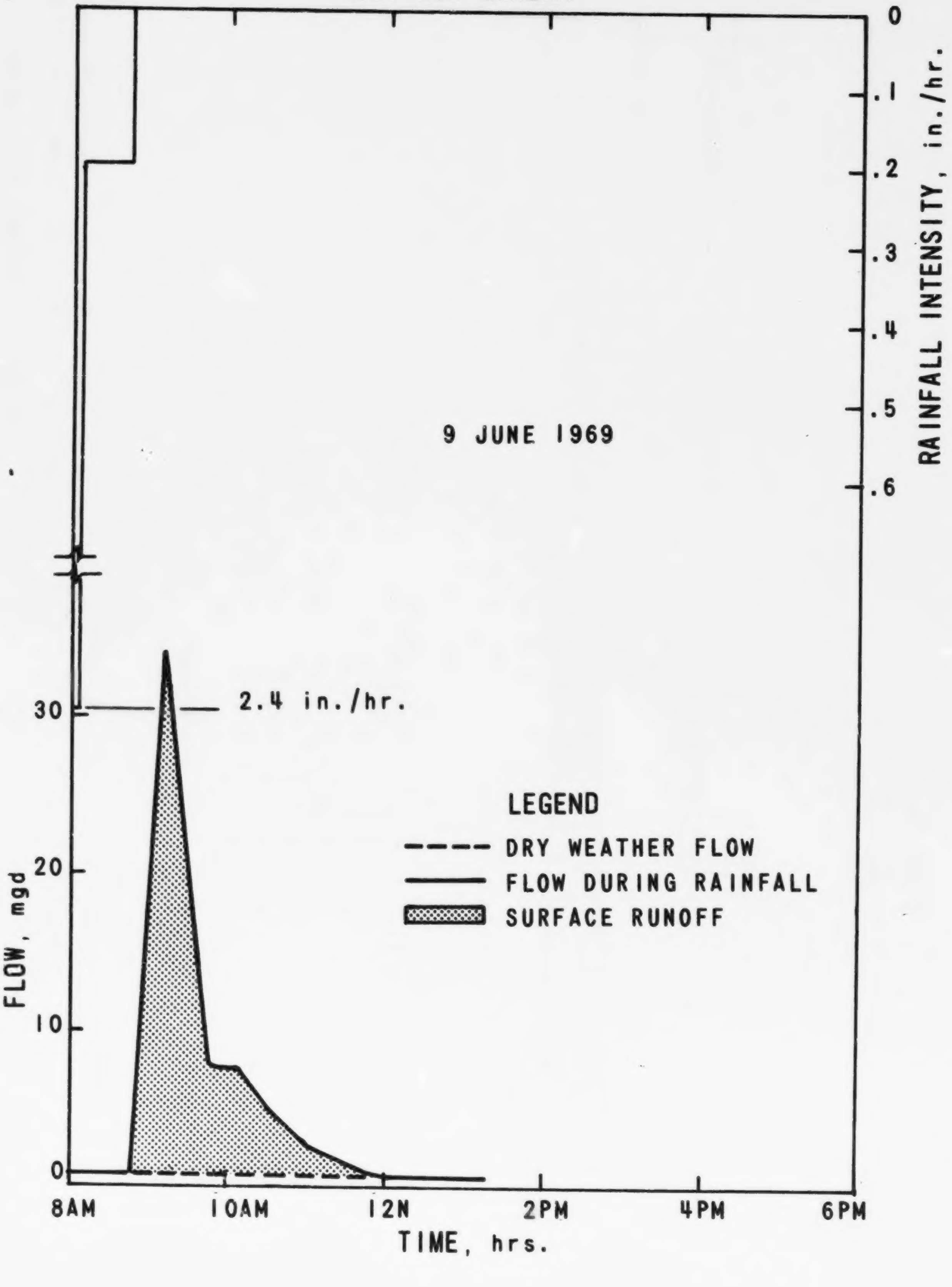


FIGURE 45 RAINFALL INTENSITY AND RATE OF DISCHARGE TROUT RUN STREAM

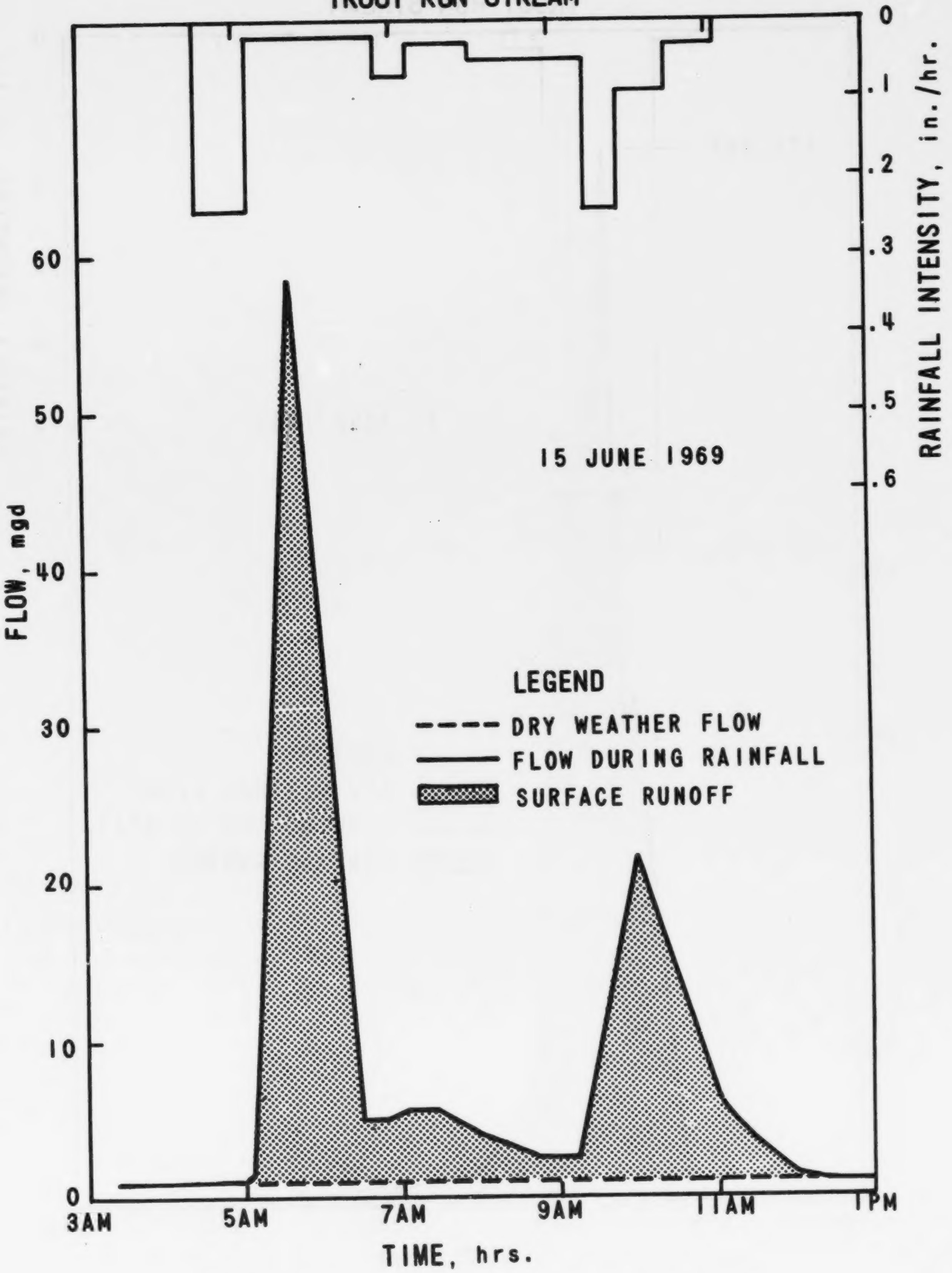


FIGURE 46 RAINFALL INTENSITY AND RATE OF DISCHARGE
TROUT RUN STREAM

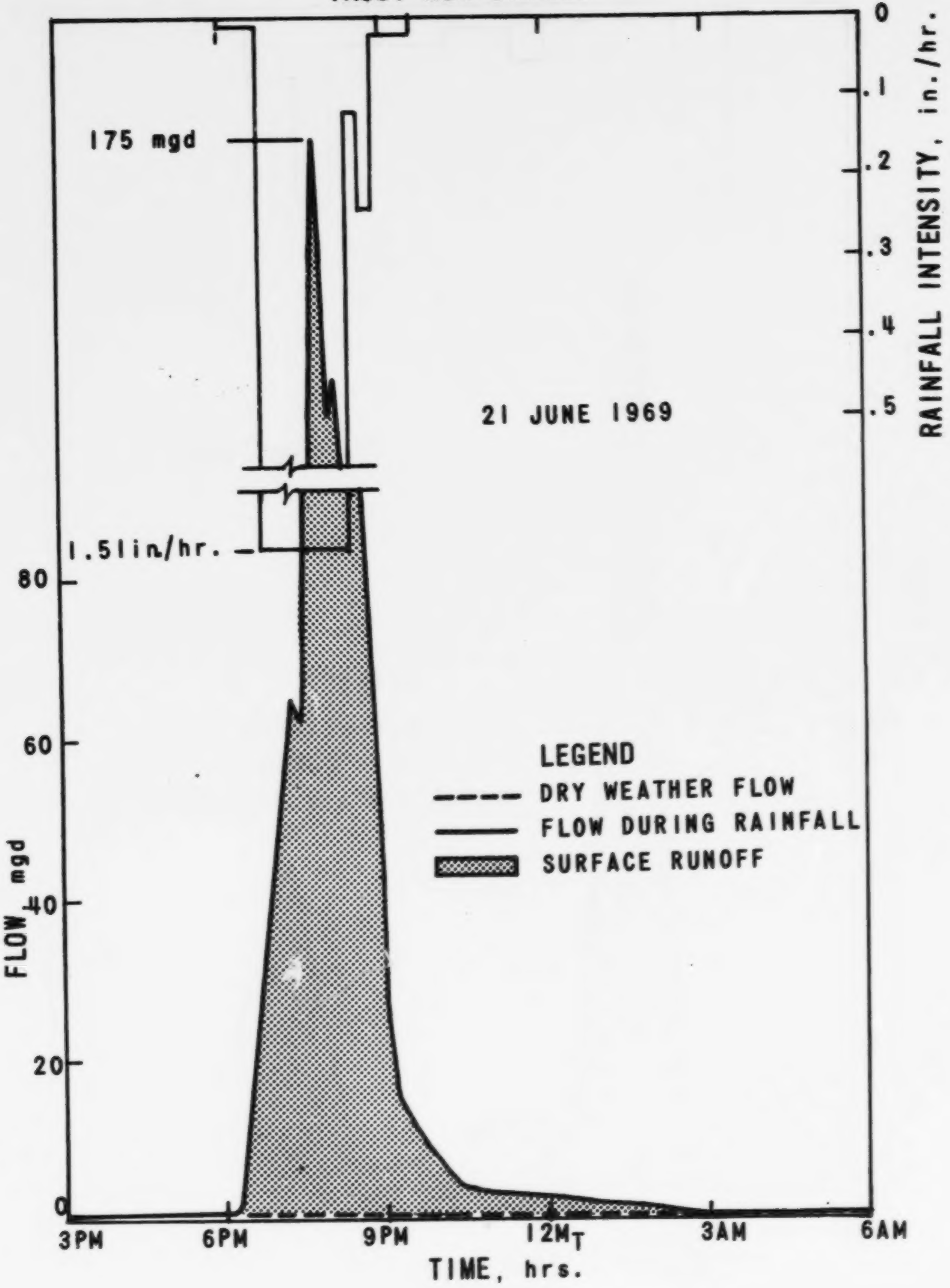


FIGURE 47 RAINFALL INTENSITY AND RATE OF DISCHARGE TROUT RUN STREAM

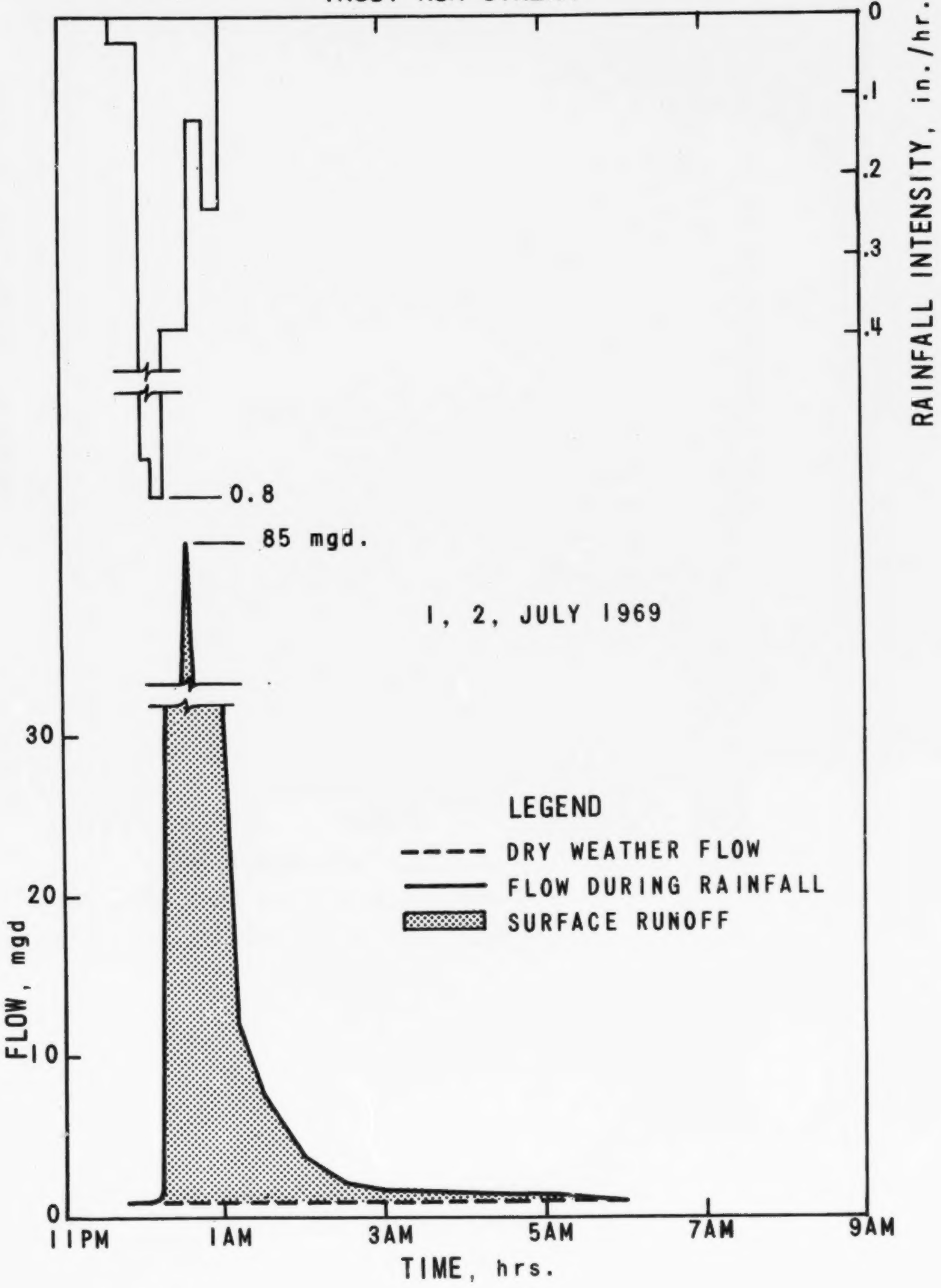


FIGURE 48 RAINFALL INTENSITY AND RATE OF DISCHARGE TROUT RUN STREAM

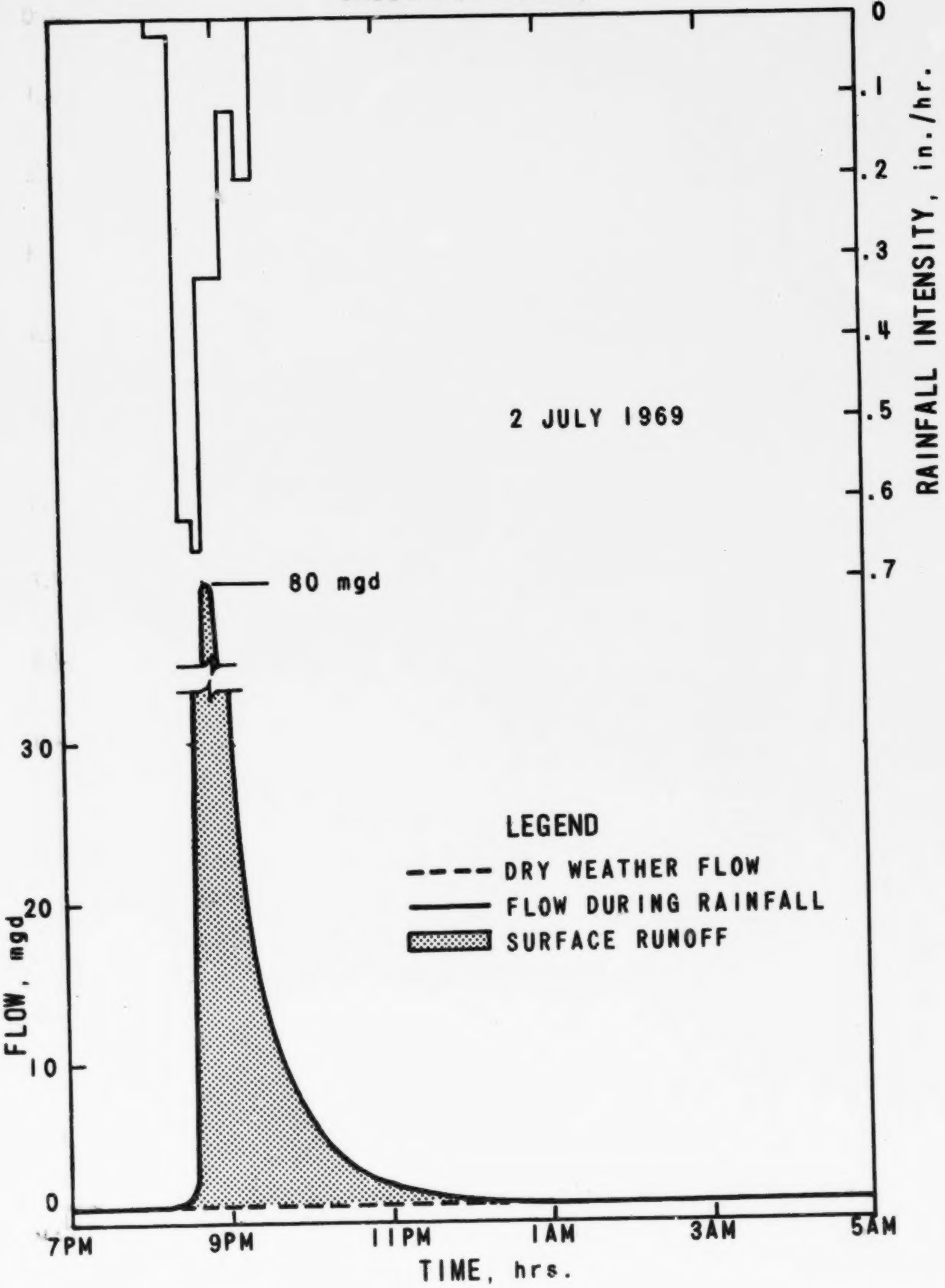


FIGURE 49 RAINFALL INTENSITY AND RATE OF DISCHARGE
TROUT RUN STREAM

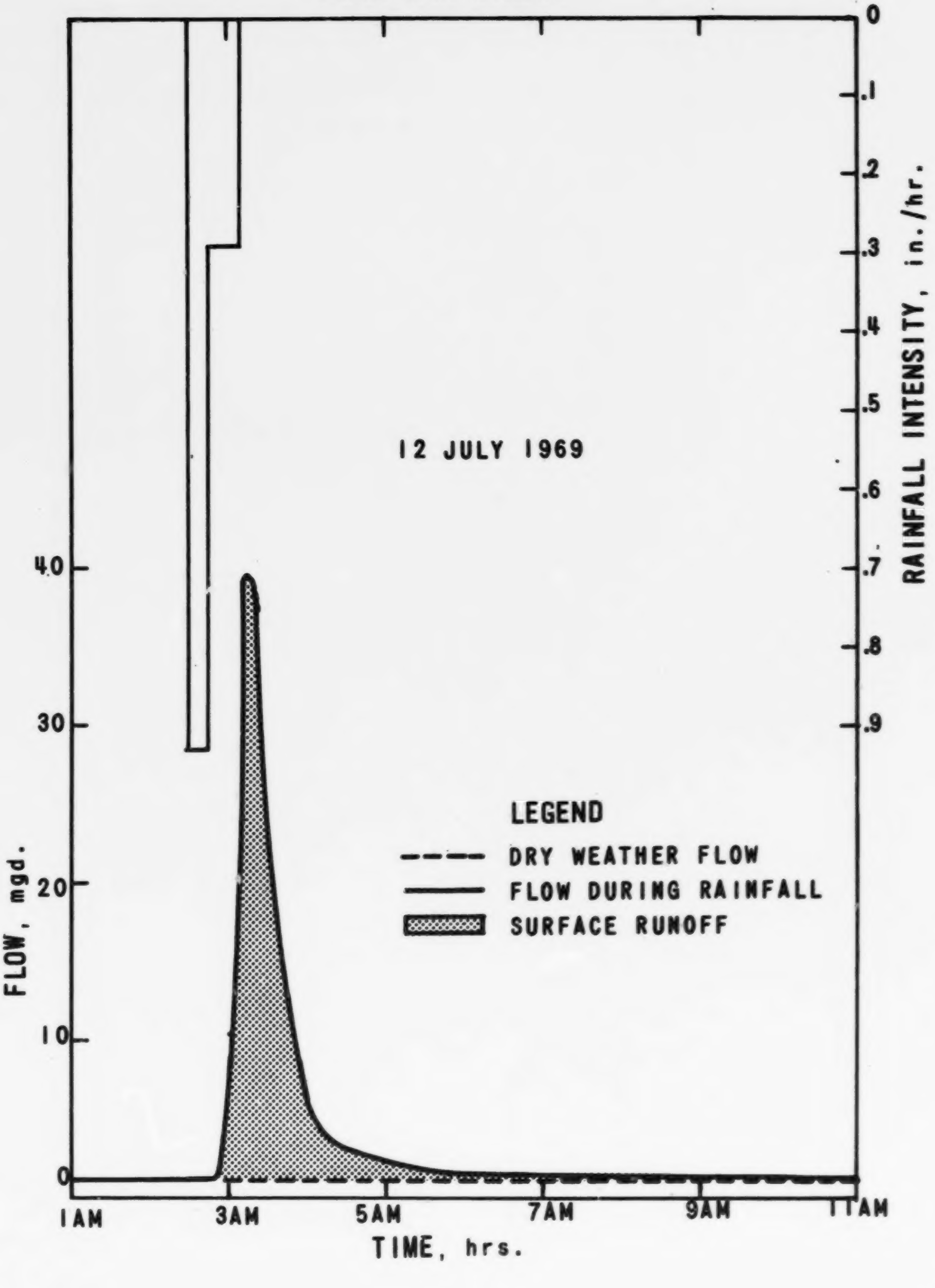


FIGURE 50 RAINFALL INTENSITY AND RATE OF DISCHARGE TROUT RUN STREAM

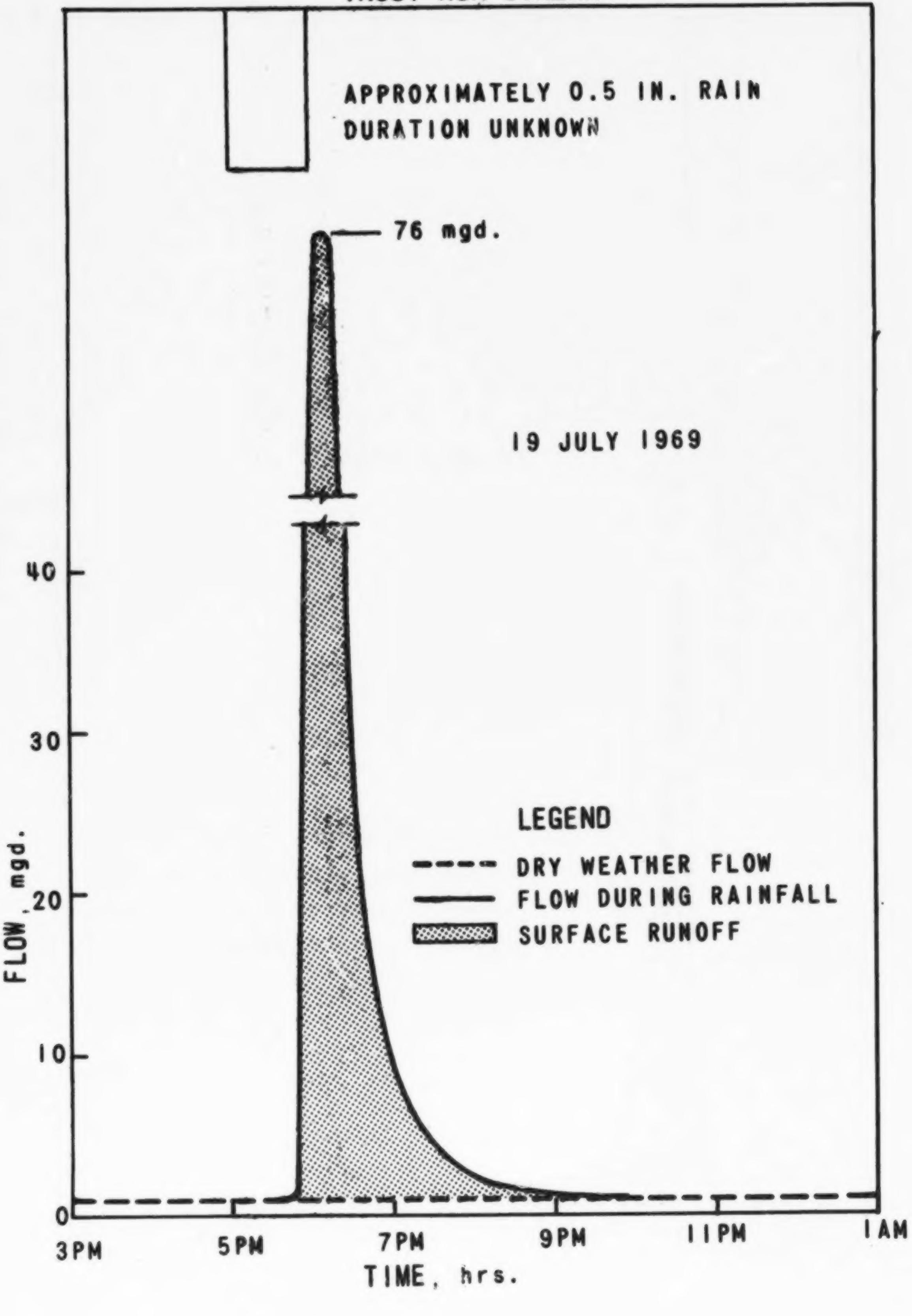


FIGURE 51 RAINFALL INTENSITY AND RATE OF DISCHARGE TROUT RUN STREAM

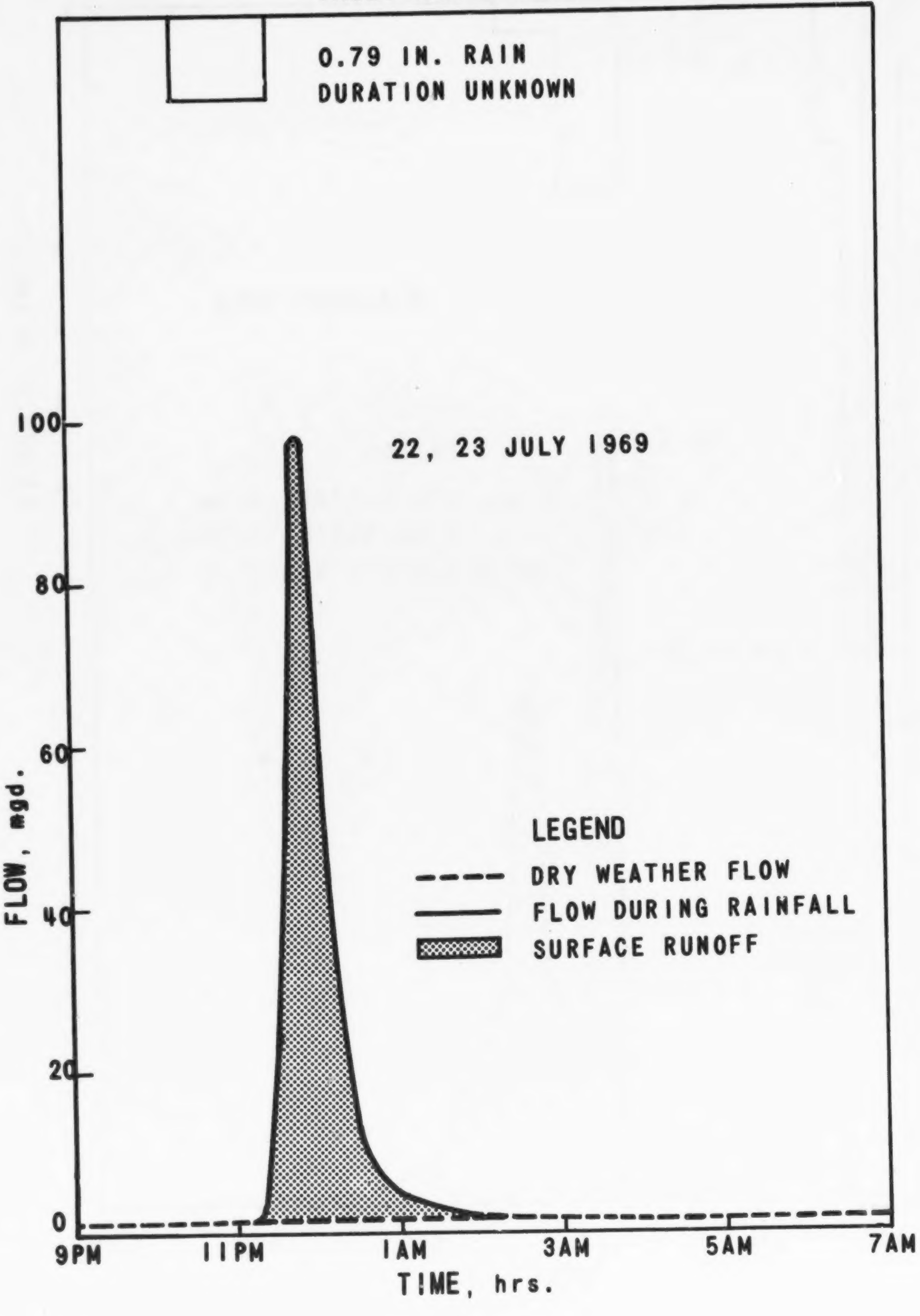


FIGURE 52 RAINFALL INTENSITY AND RATE OF DISCHARGE
TROUT RUN STREAM

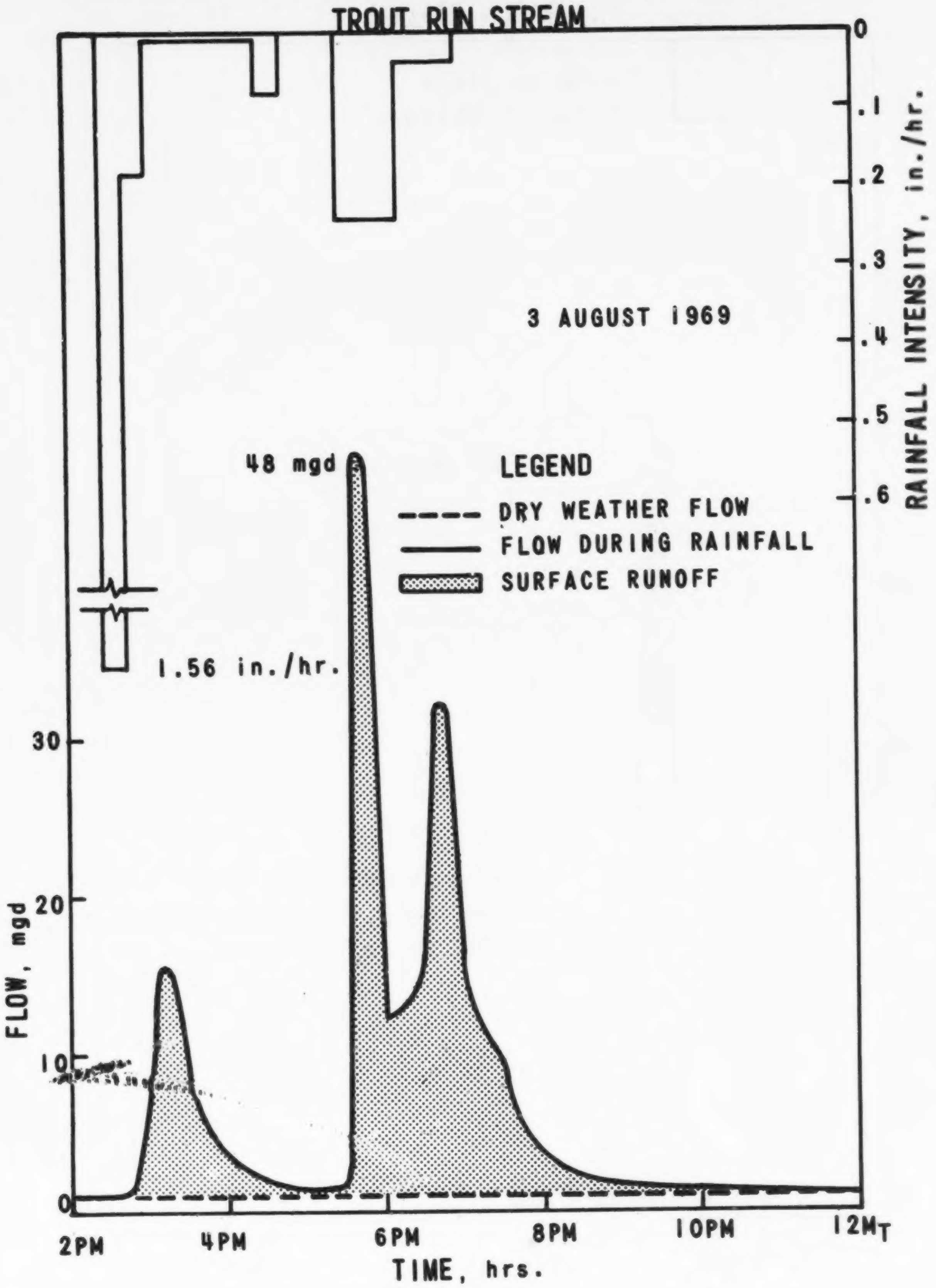


FIGURE 53 RAINFALL INTENSITY AND RATE OF DISCHARGE
24th STREET STREAM

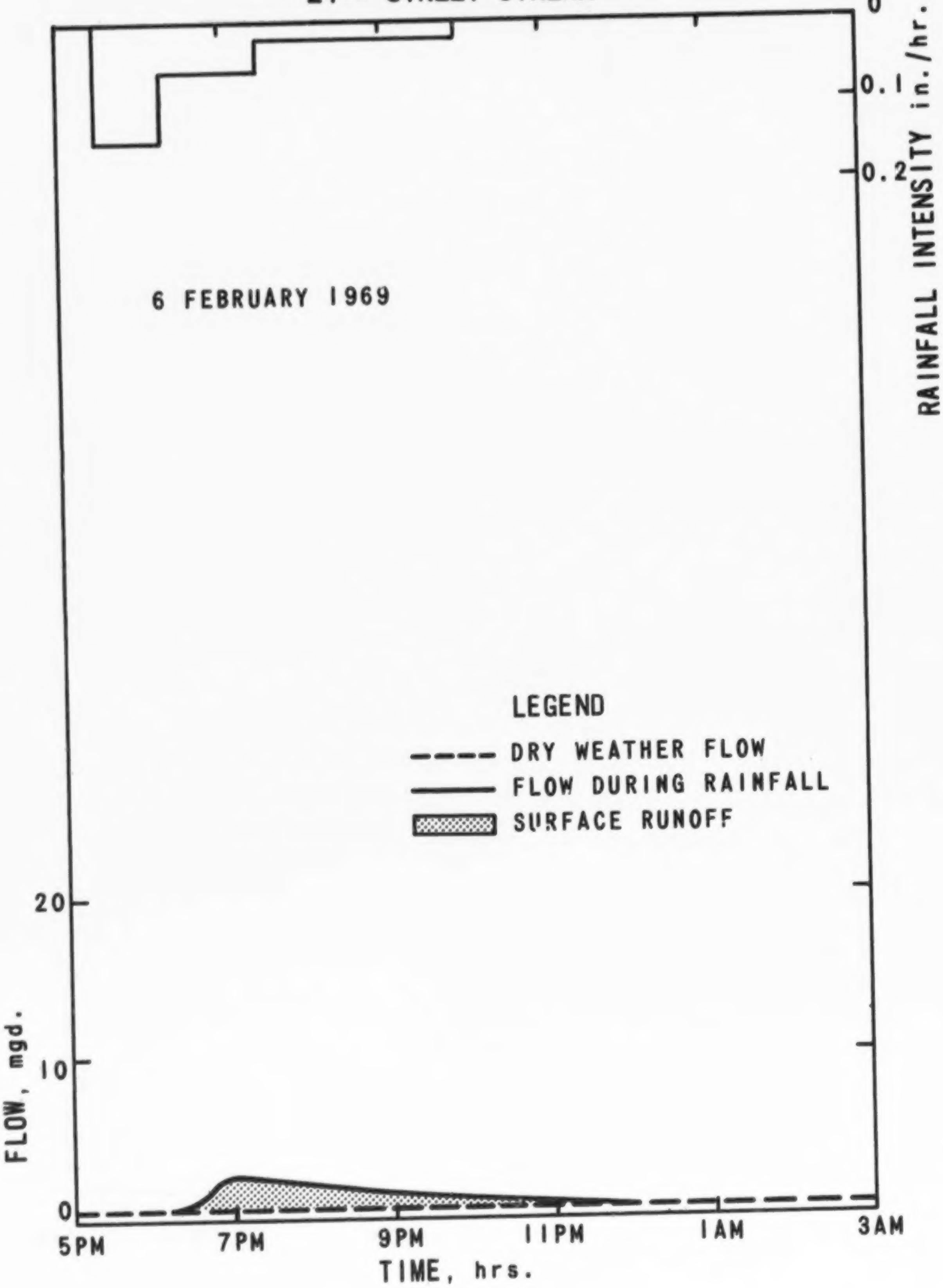


FIGURE 54 RAINFALL INTENSITY AND RATE OF DISCHARGE
24th STREET STREAM

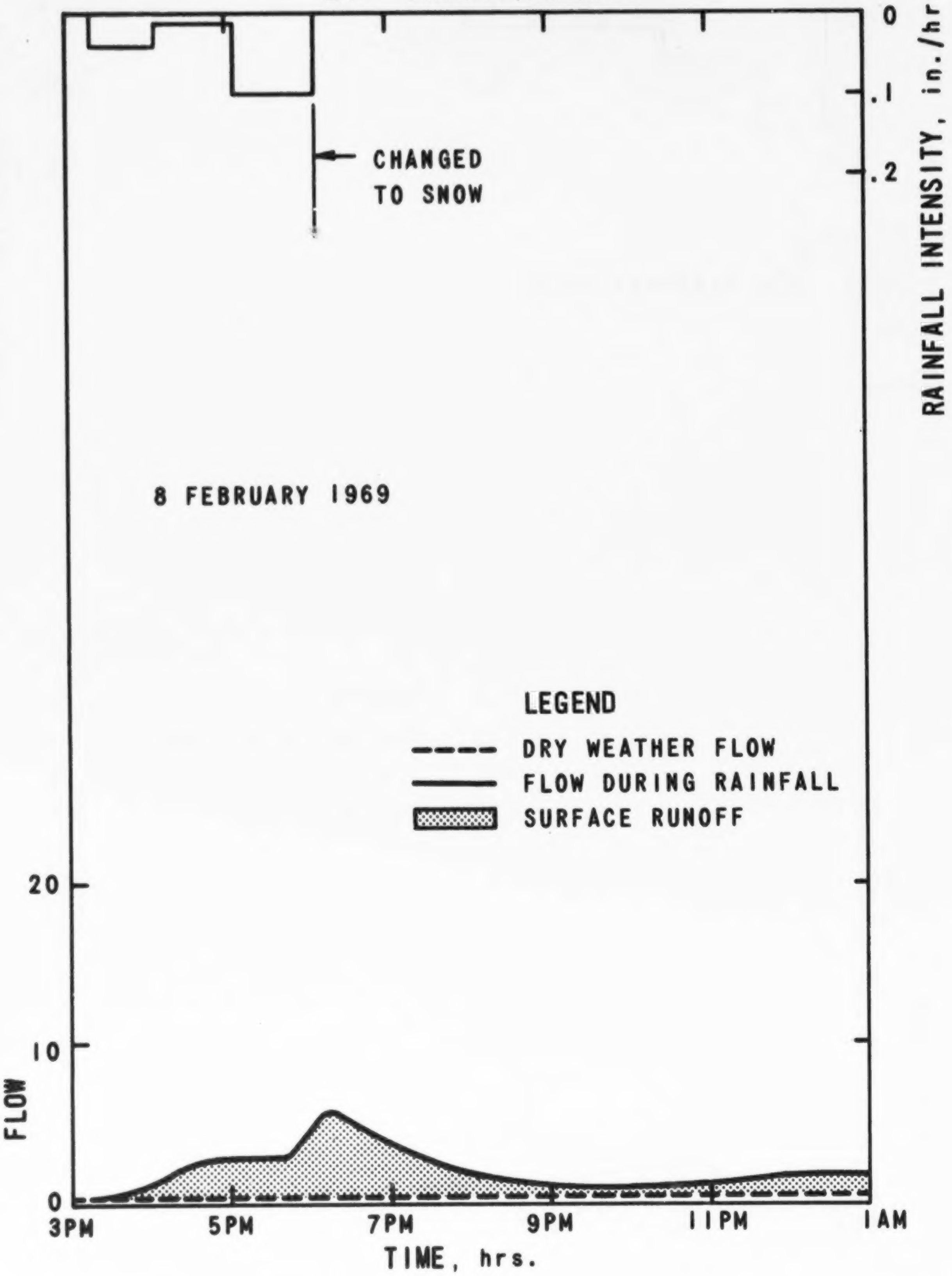
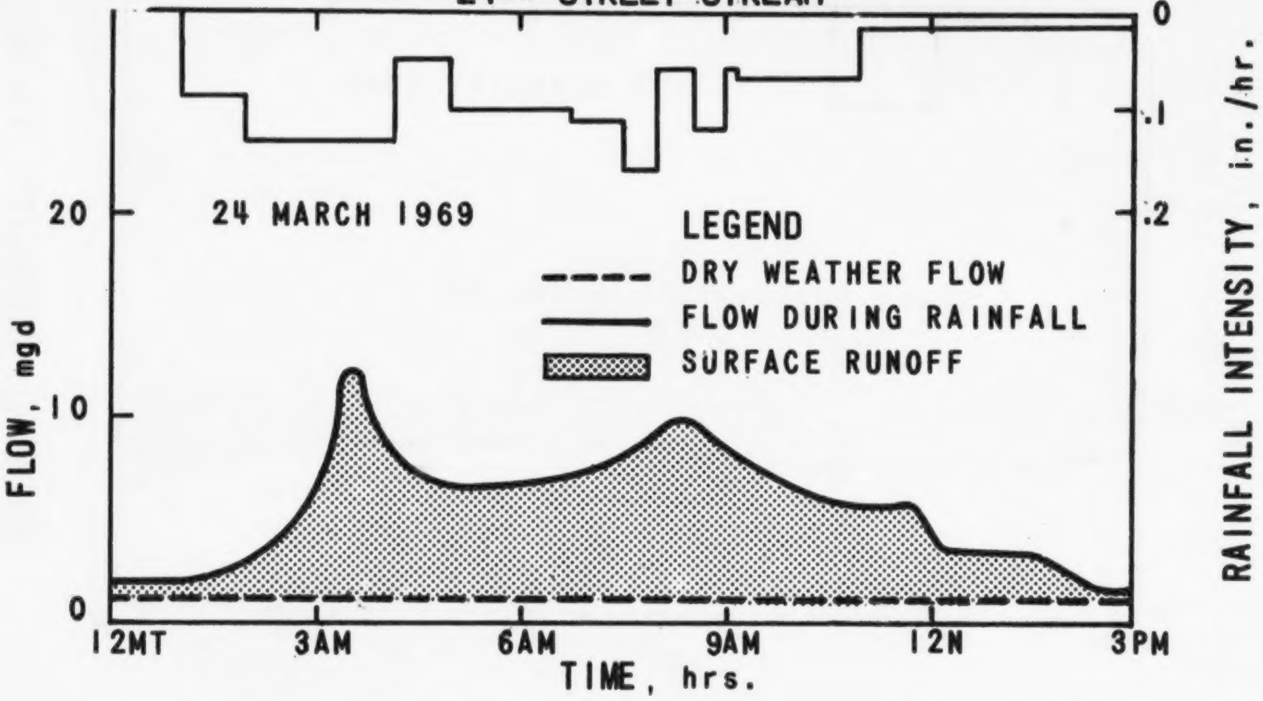


FIGURE 55 RAINFALL INTENSITY AND RATE OF DISCHARGE

24th STREET STREAM



24th STREET STREAM

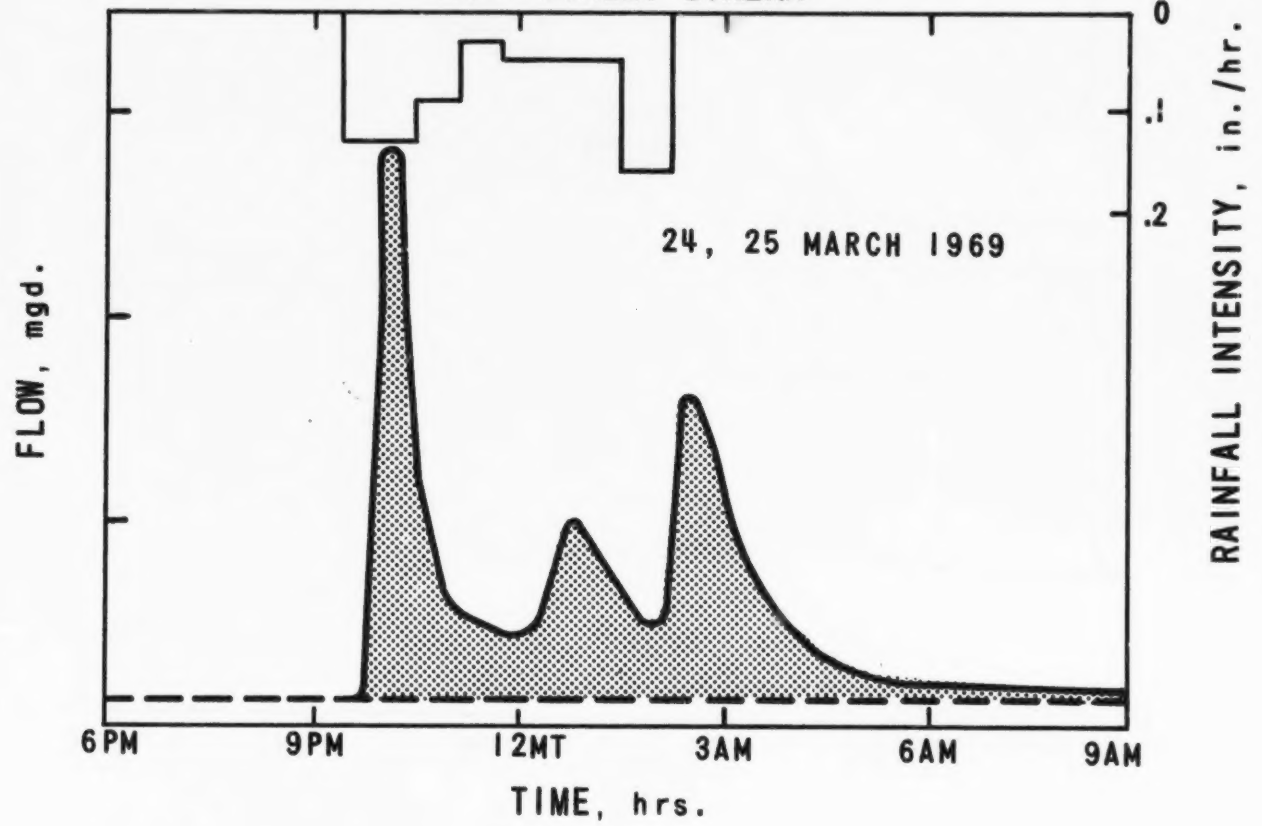


FIGURE 56 RAINFALL INTENSITY AND RATE OF DISCHARGE MURRAY RUN SANITARY SEWER

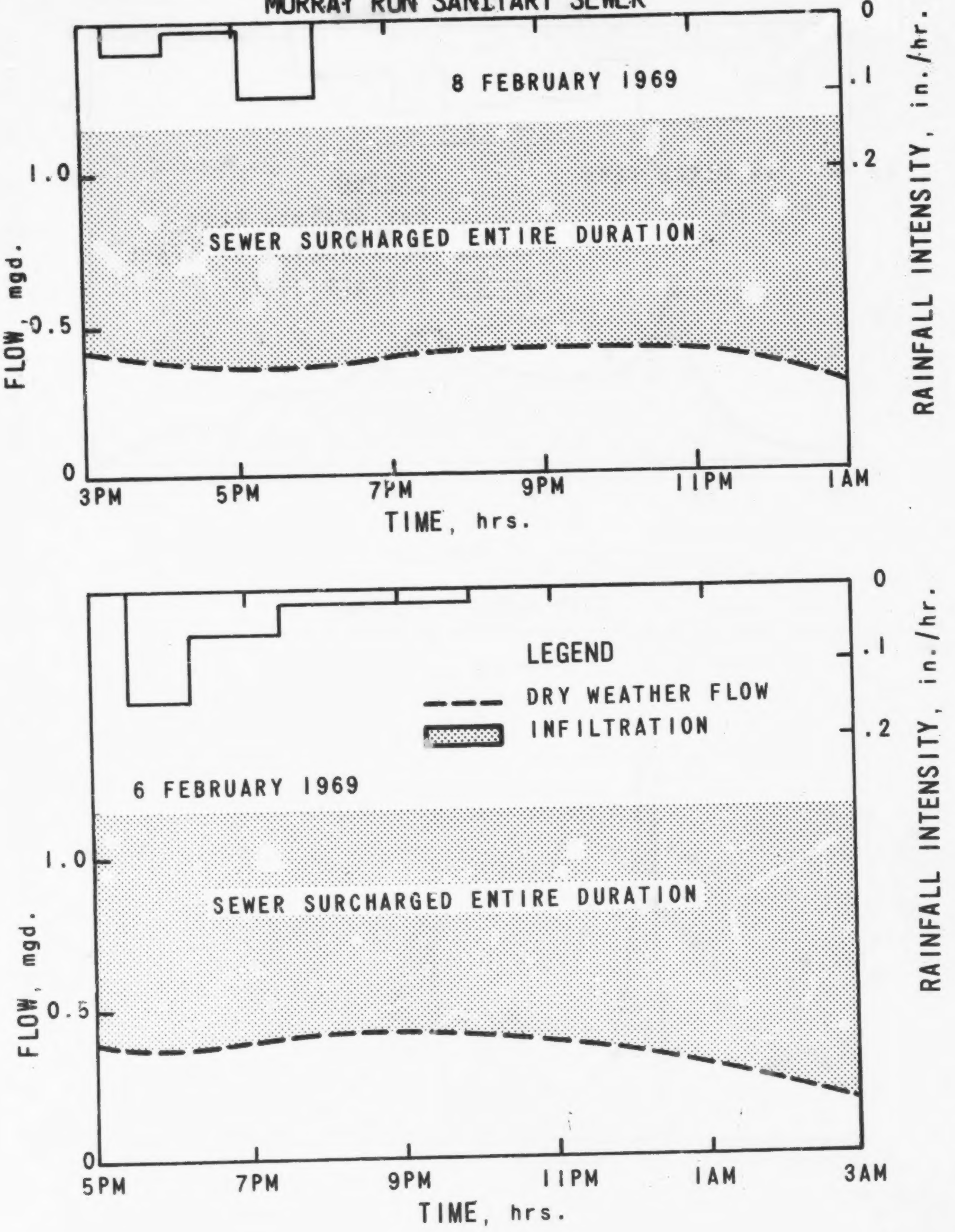


FIGURE 57 RAINFALL INTENSITY AND RATE OF DISCHARGE
MURRAY RUN SANITARY SEWER

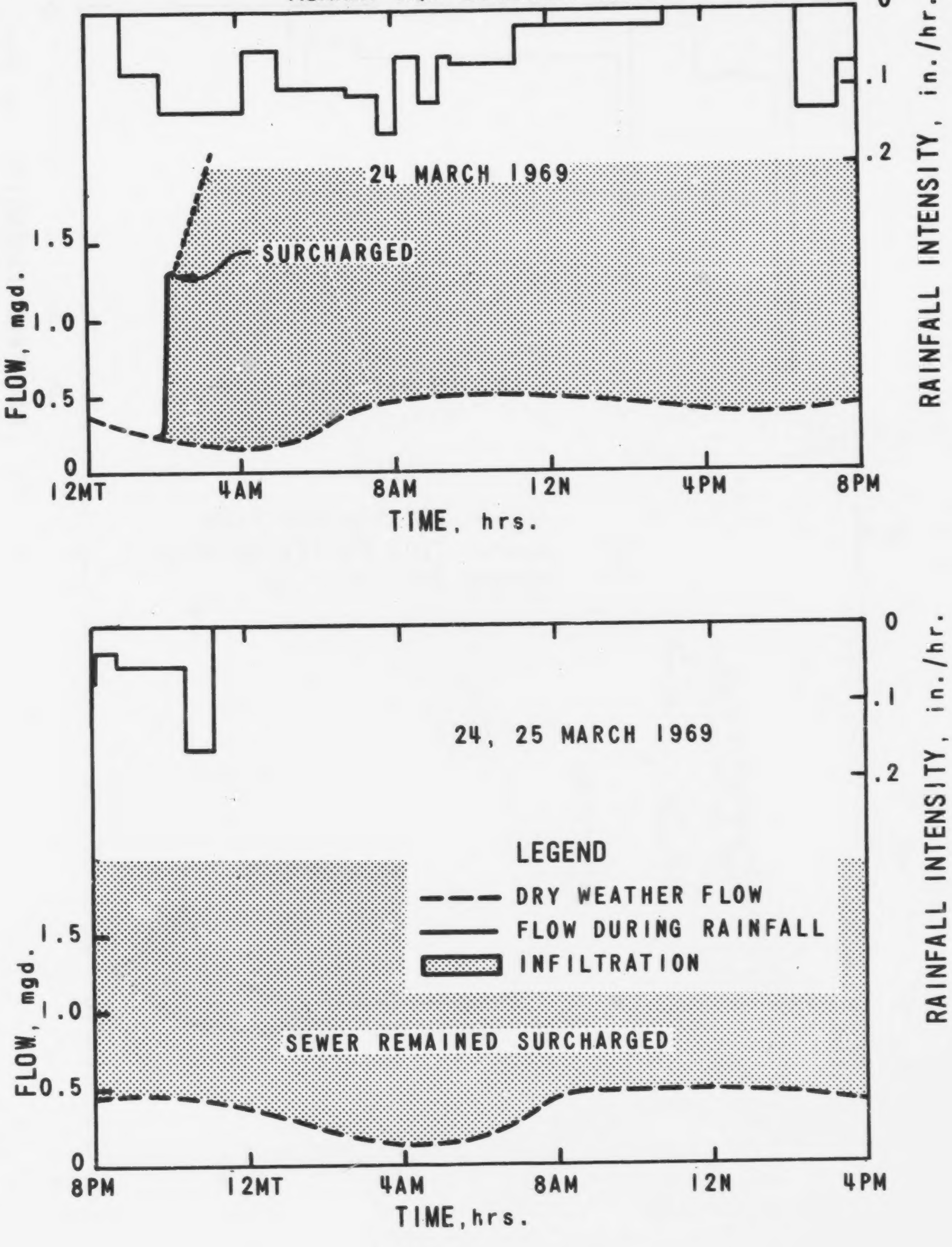


FIGURE 58 RAINFALL INTENSITY AND RATE OF DISCHARGE MURRAY RUN SANITARY SEWER

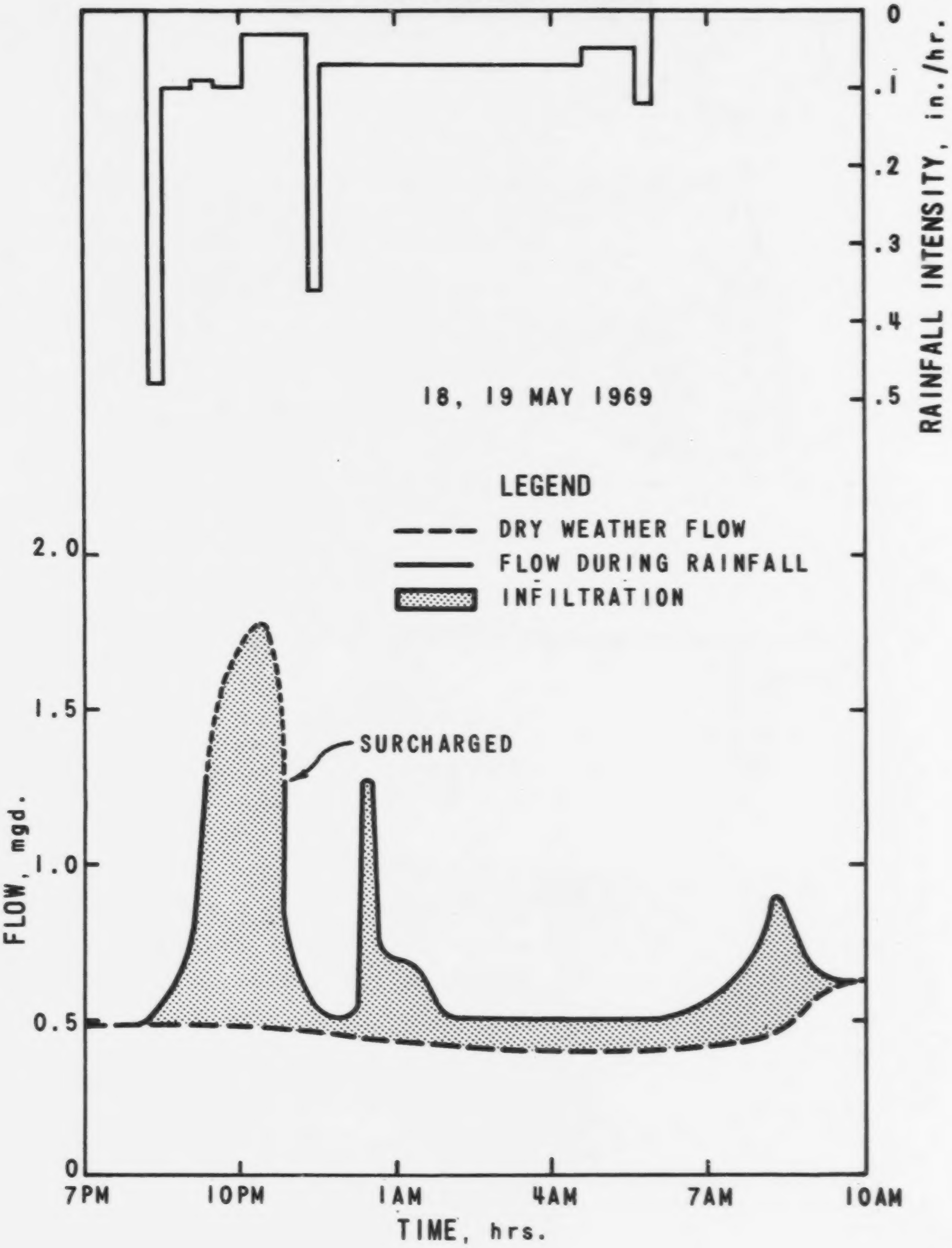


FIGURE 59 RAINFALL INTENSITY AND RATE OF DISCHARGE
MURRAY RUN SANITARY SEWER

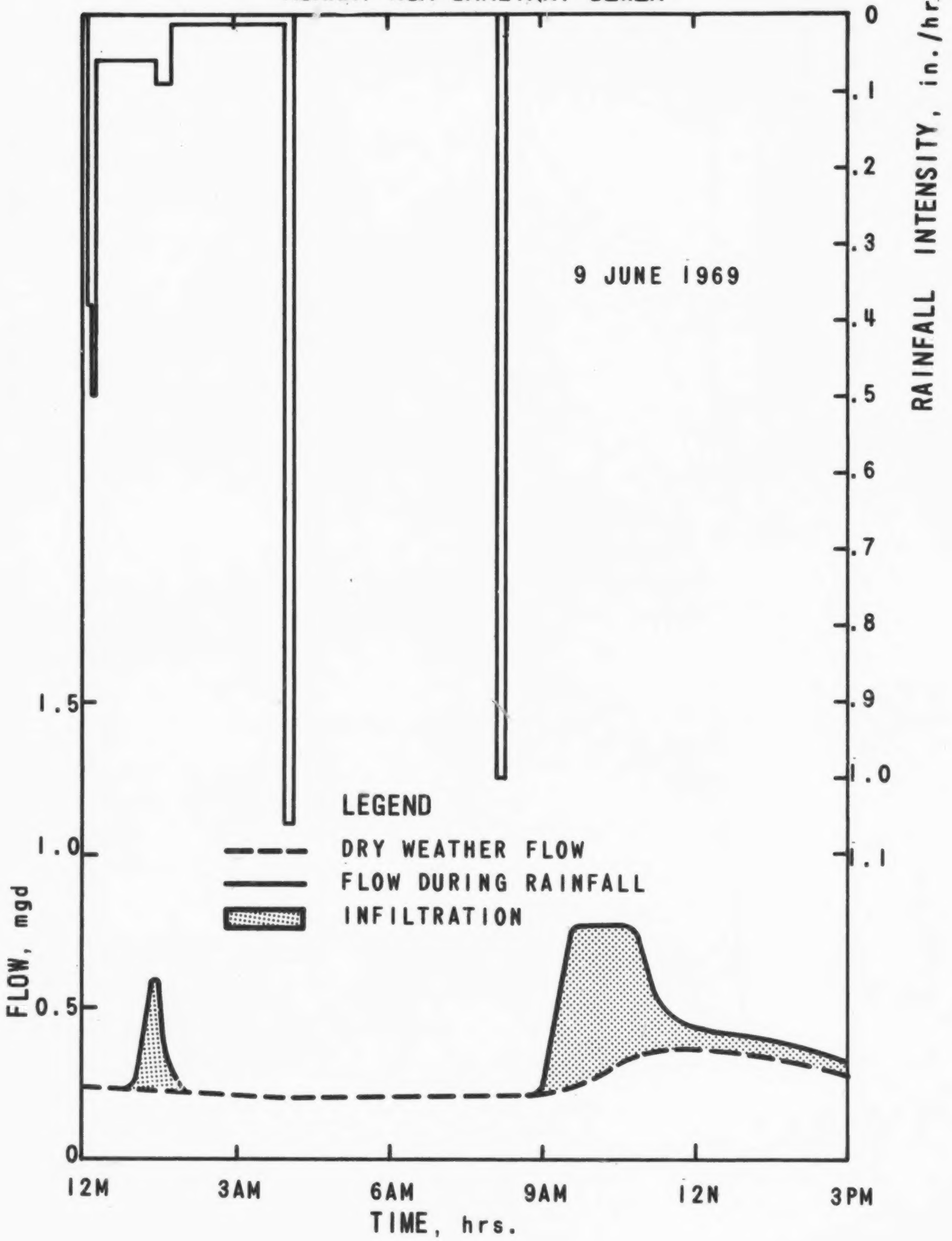


FIGURE 60 RAINFALL INTENSITY AND RATE OF DISCHARGE MURRAY RUN SANITARY SEWER

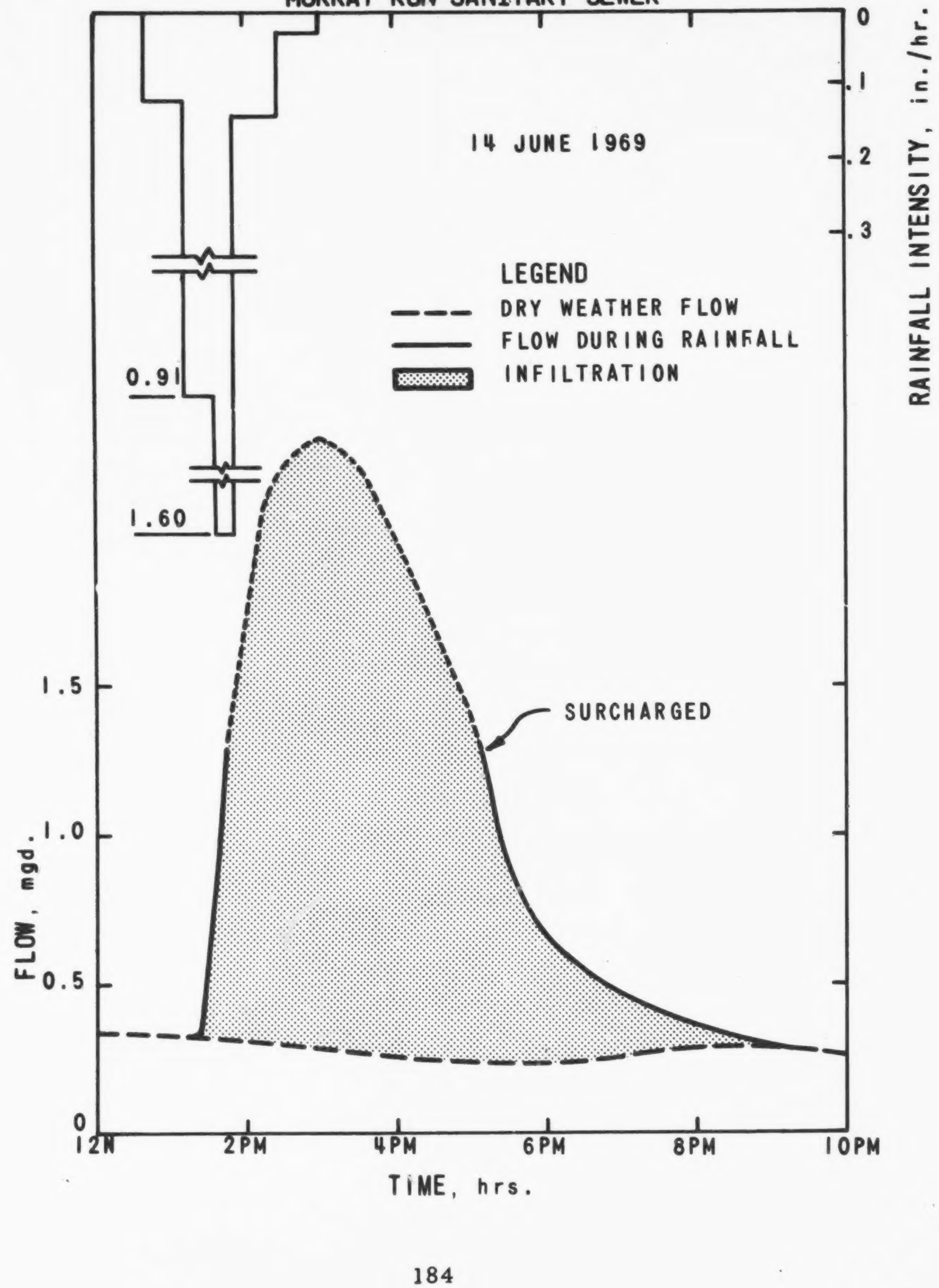


FIGURE 61 RAINFALL INTENSITY AND RATE OF DISCHARGE MURRAY RUN SANITARY SEWER

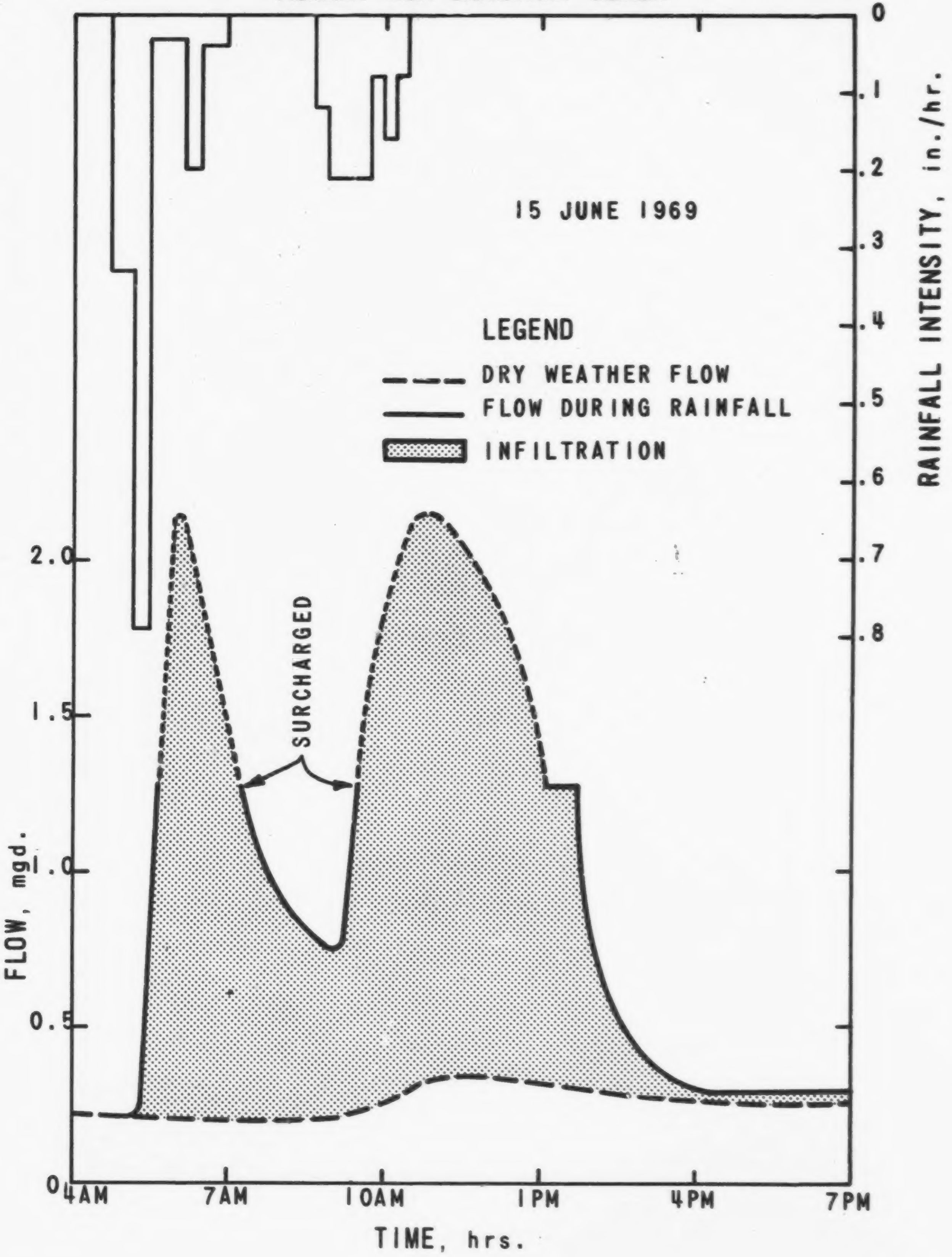


FIGURE 62 RAINFALL INTENSITY AND RATE OF DISCHARGE MURRAY RUN SANITARY SEWER

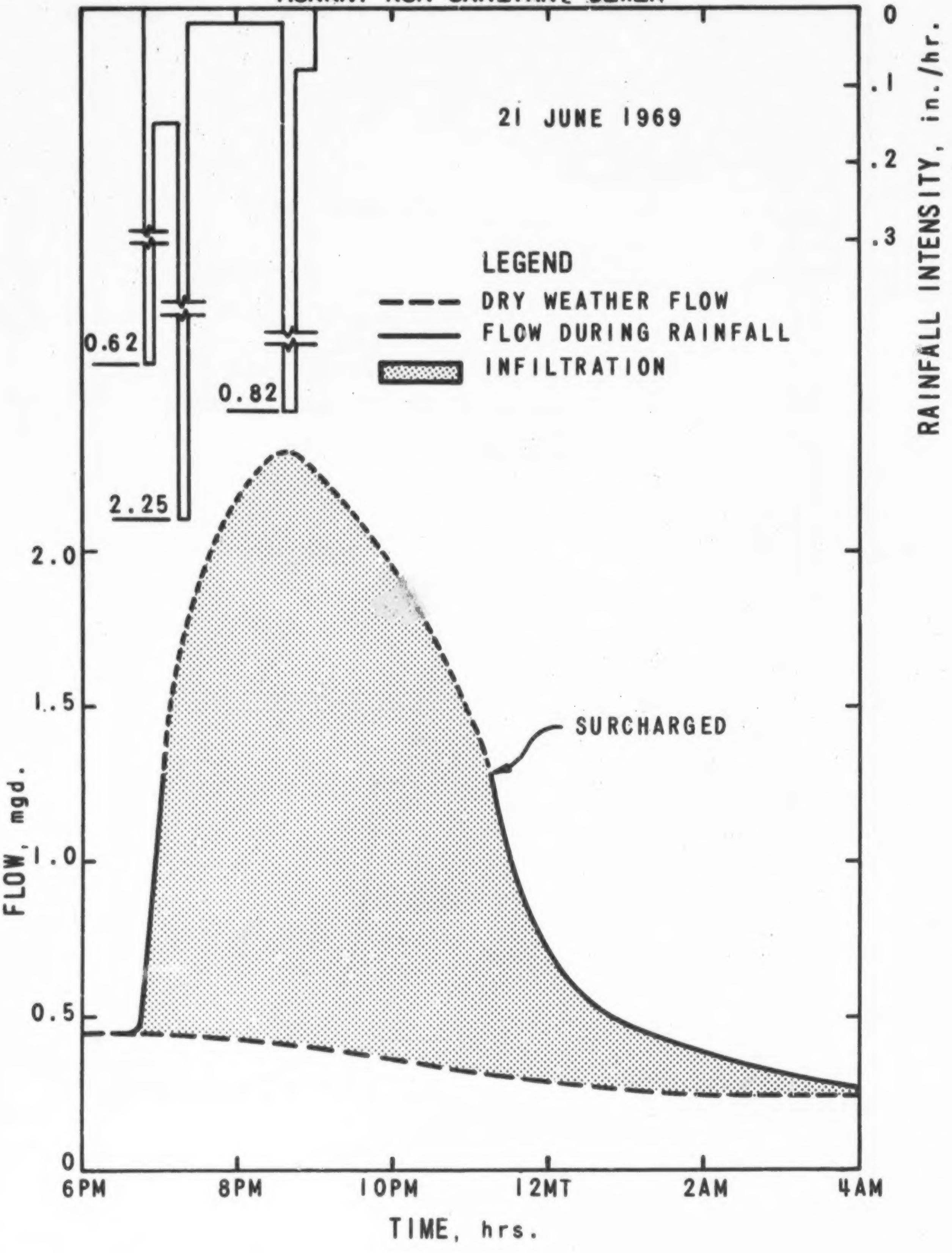


FIGURE 63 RAINFALL INTENSITY AND RATE OF DISCHARGE
MURRAY RUN SANITARY SEWER

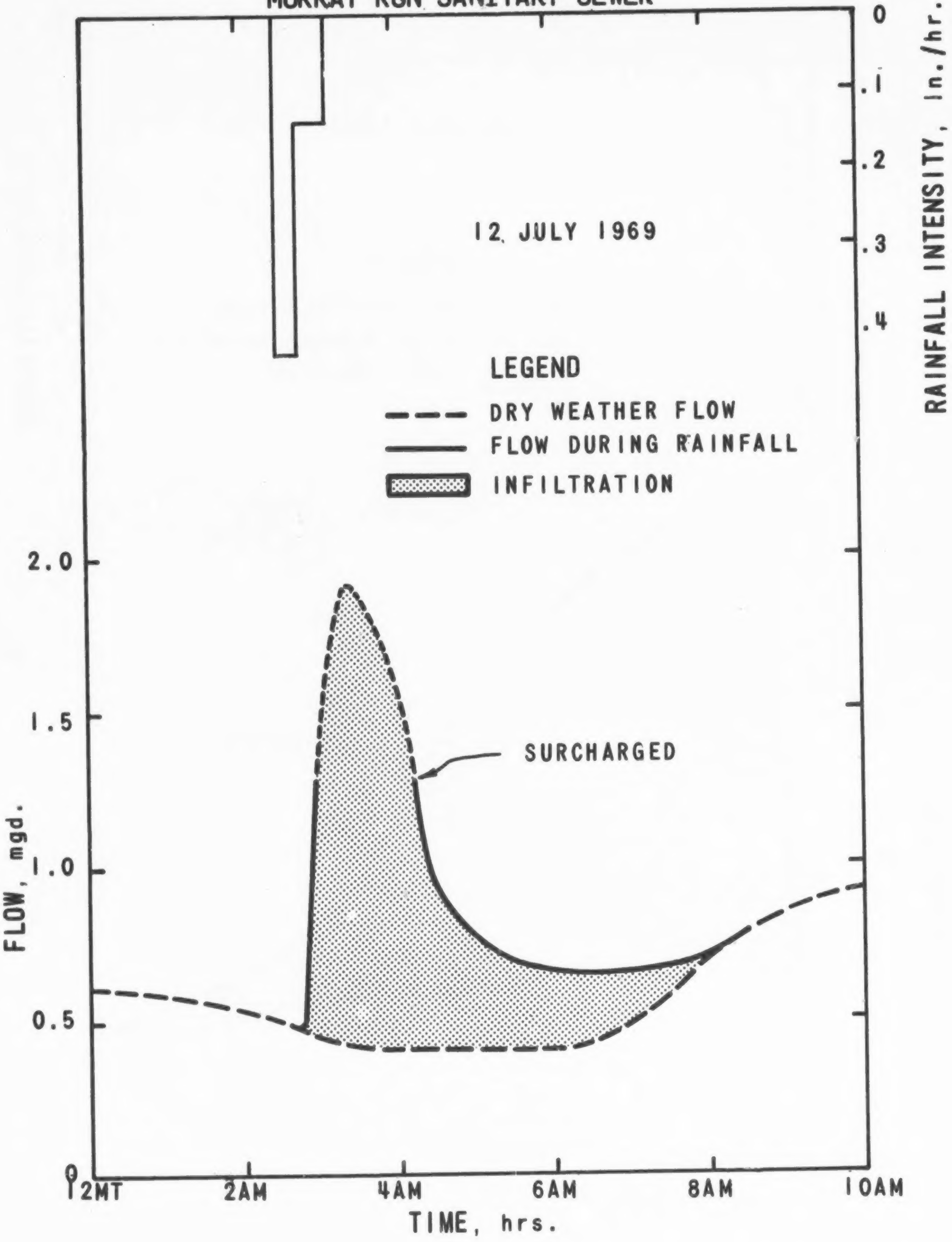


FIGURE 64 RAINFALL INTENSITY AND RATE OF DISCHARGE MURRAY RUN SANITARY SEWER

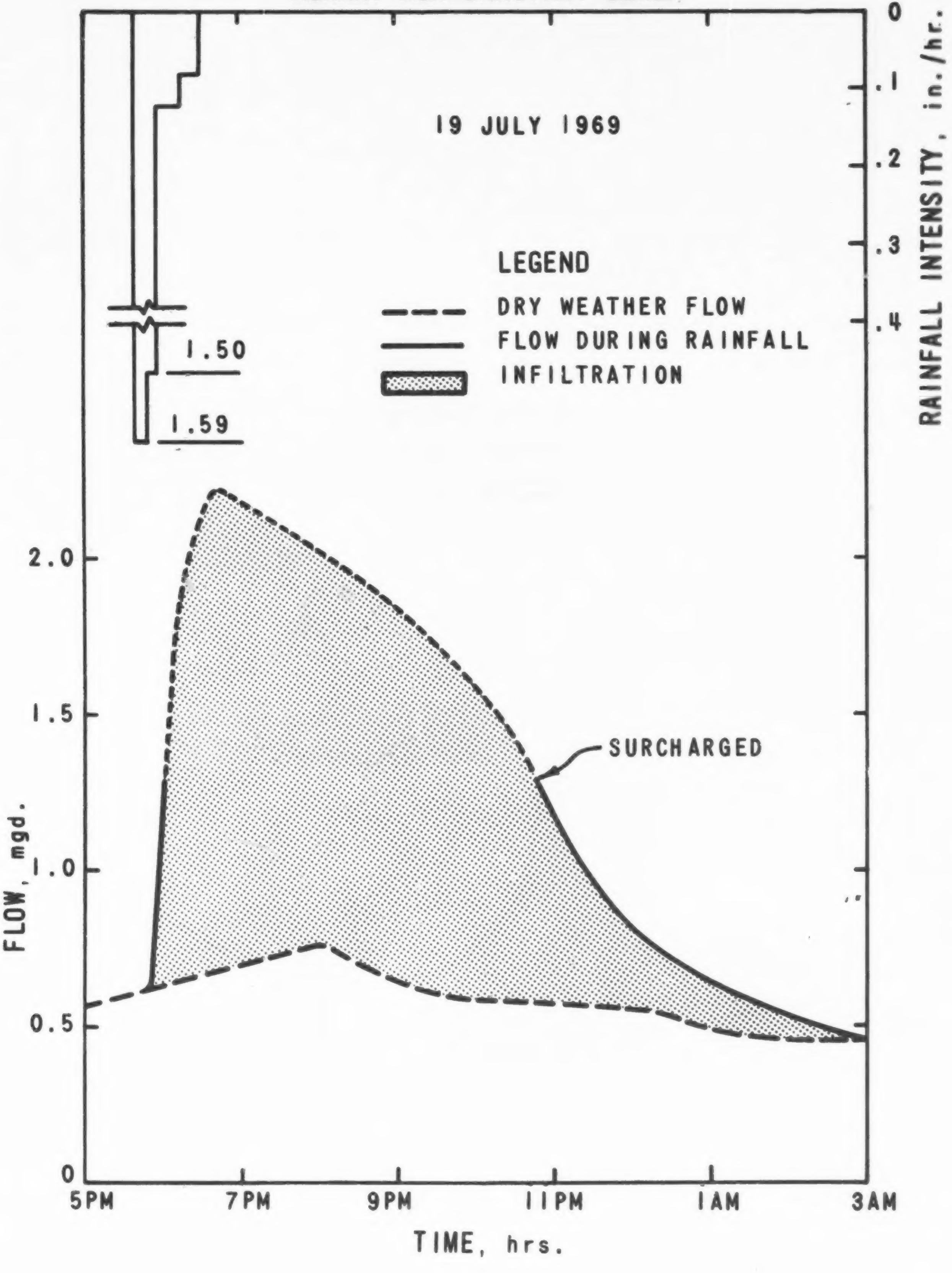


FIGURE 65 RAINFALL INTENSITY AND RATE OF DISCHARGE
MURRAY RUN SANITARY SEWER

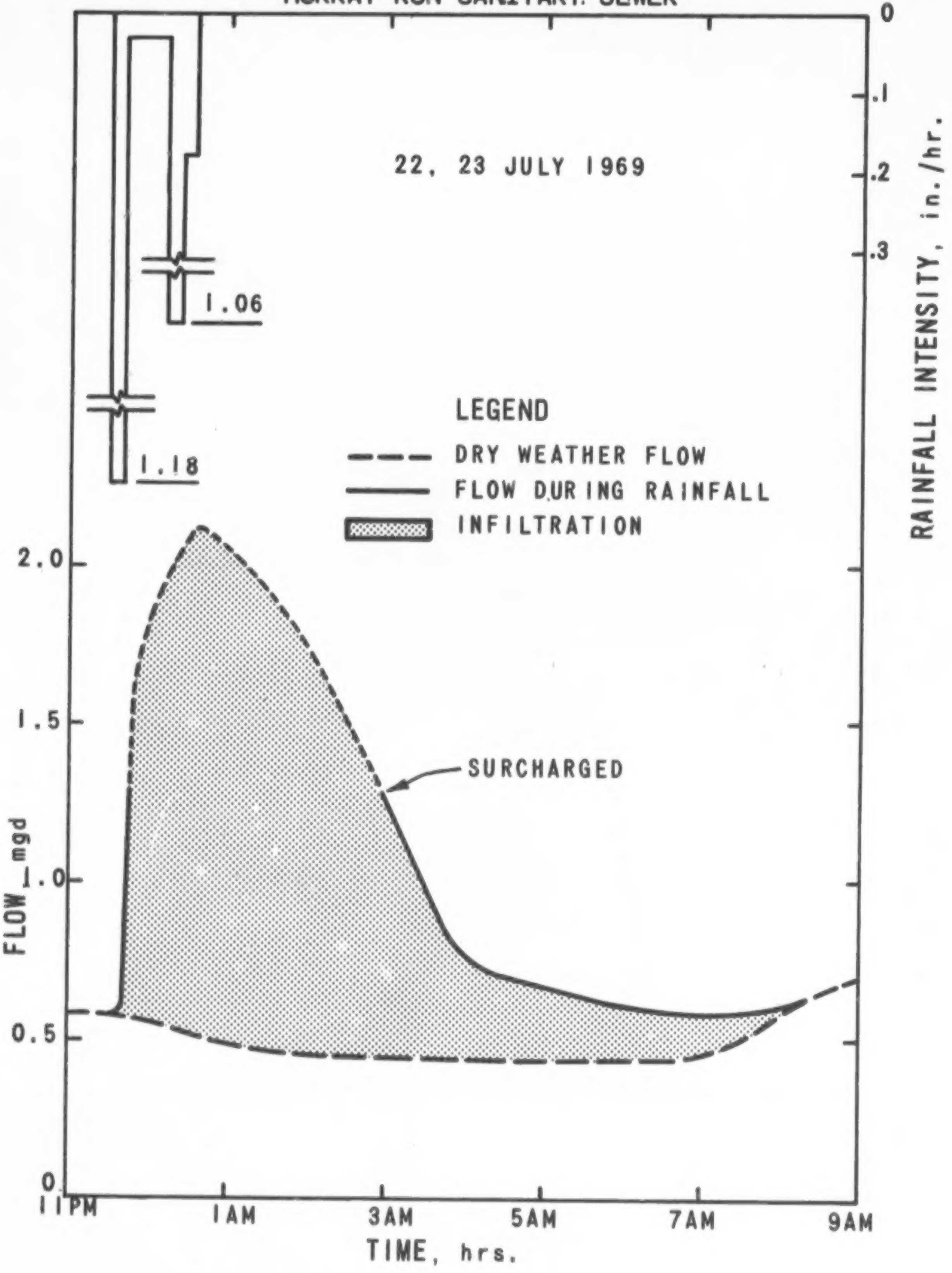


FIGURE 66 RAINFALL INTENSITY AND RATE OF DISCHARGE
MURRAY RUN SANITARY SEWER

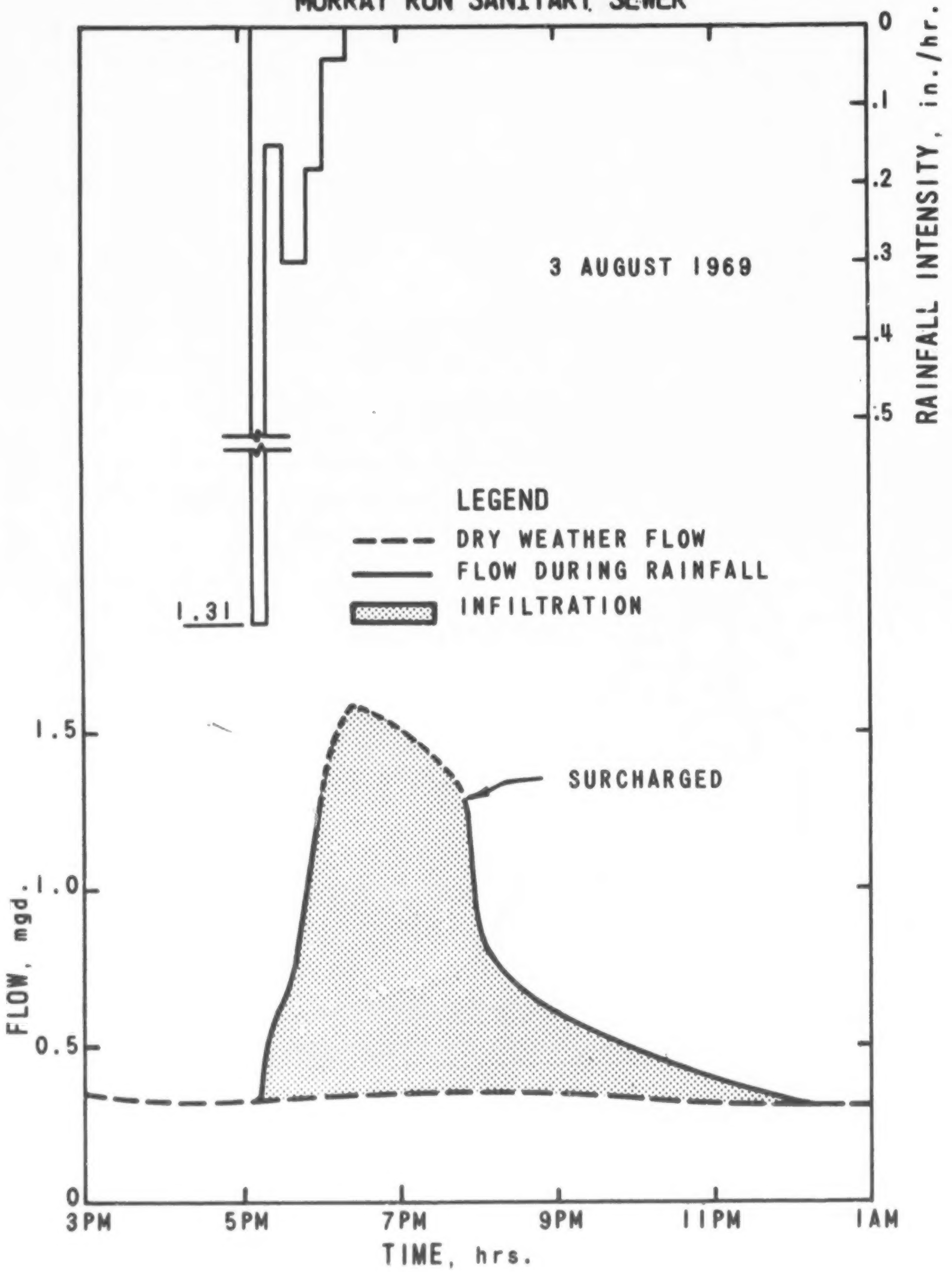


FIGURE 67 RAINFALL INTENSITY AND RATE OF DISCHARGE TROUT RUN SANITARY SEWER

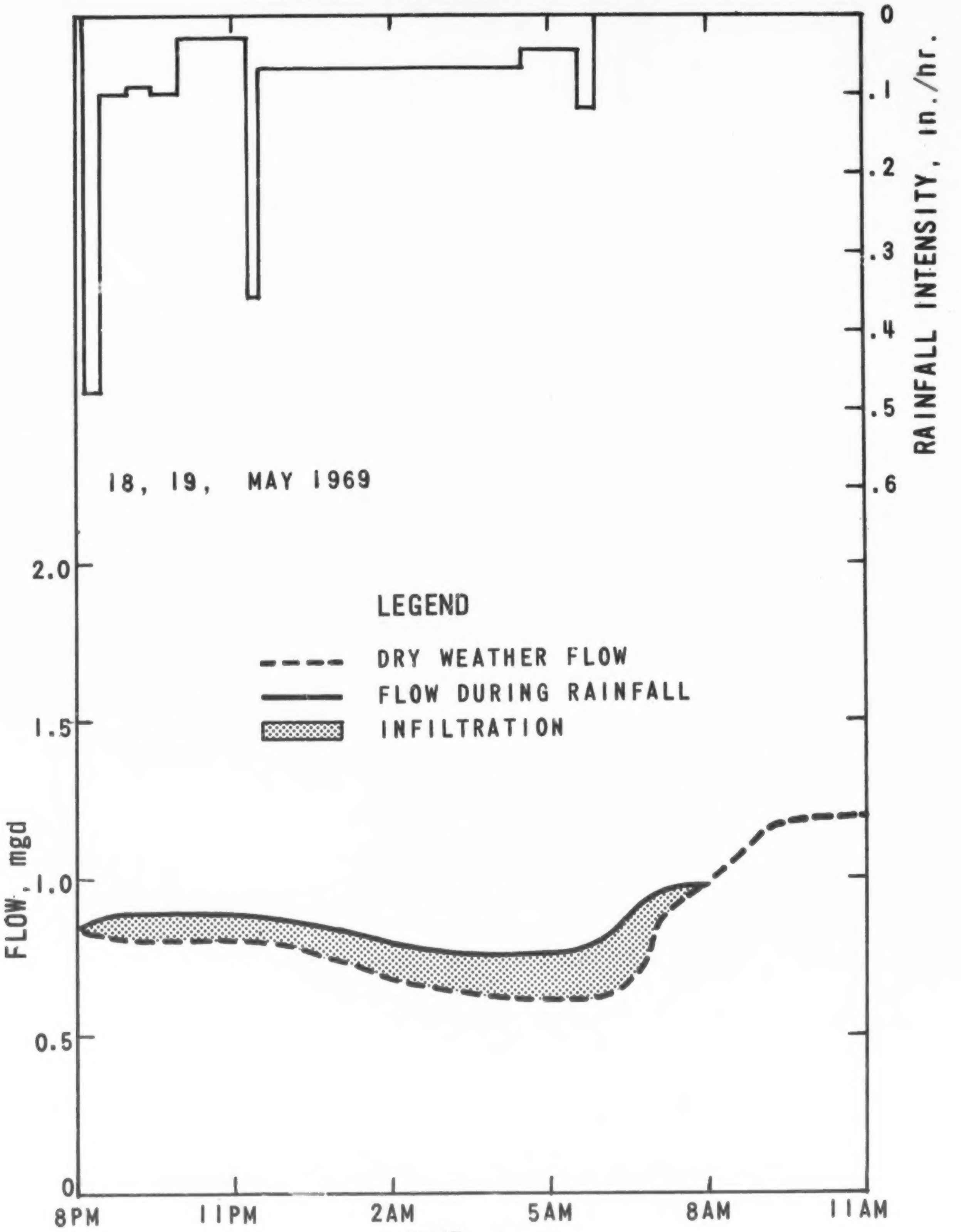


FIGURE 68 RAINFALL INTENSITY AND RATE OF DISCHARGE TROUT RUN SANITARY SEWER

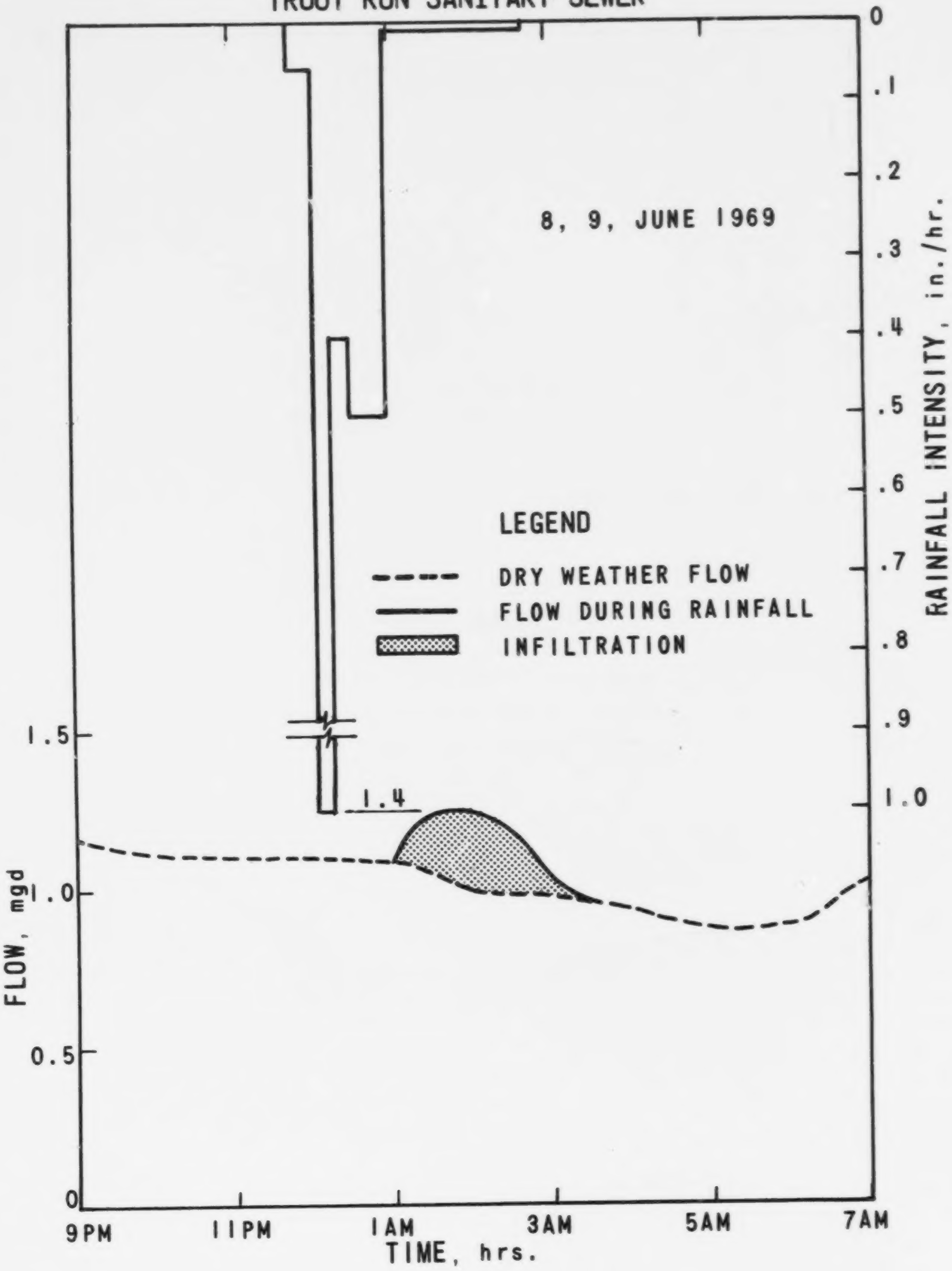


FIGURE 69 RAINFALL INTENSITY AND RATE OF DISCHARGE
TROUT RUN SANITARY SEWER

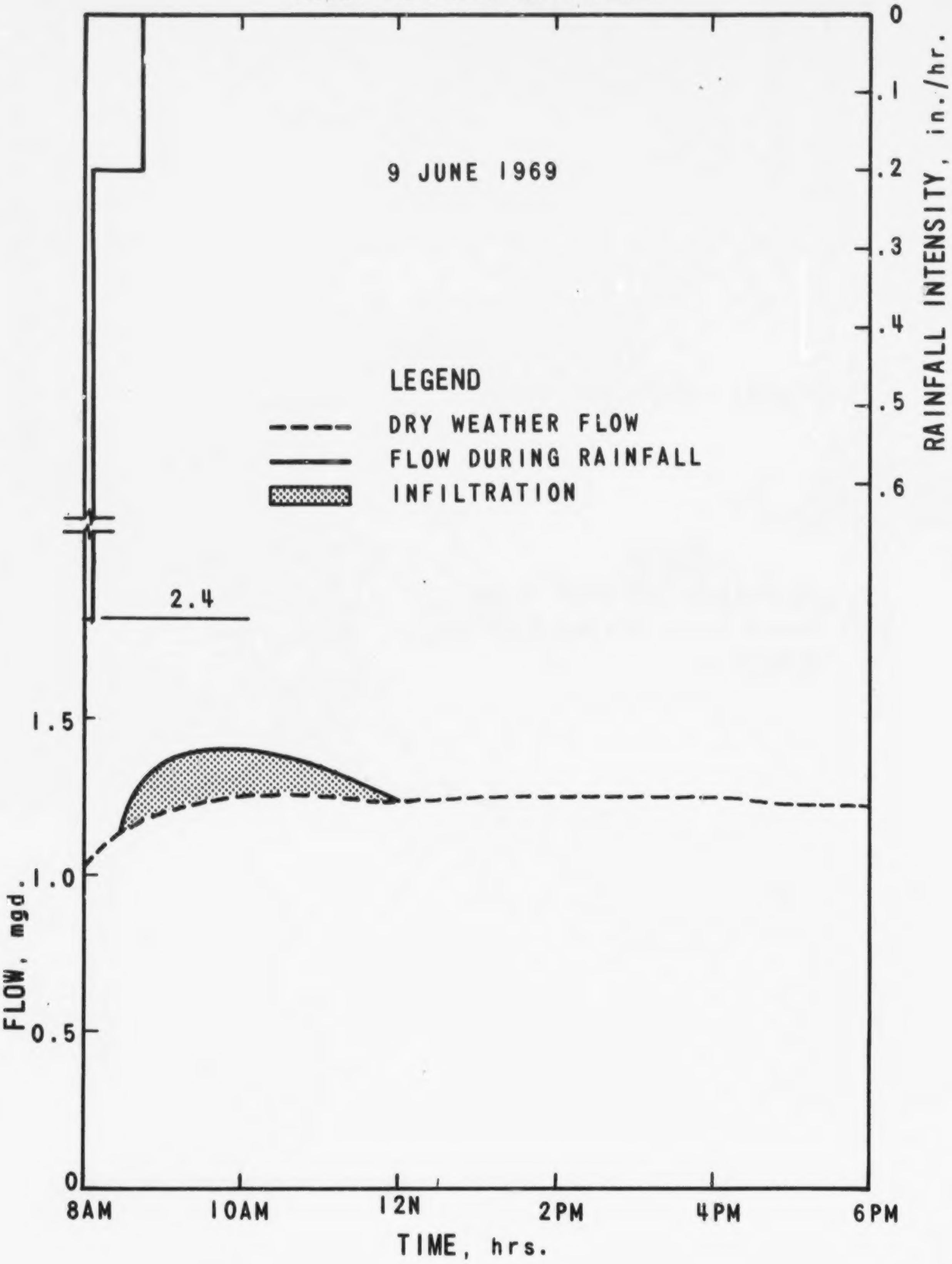


FIGURE 70 RAINFALL INTENSITY AND RATE OF DISCHARGE TROUT RUN SANITARY SEWER

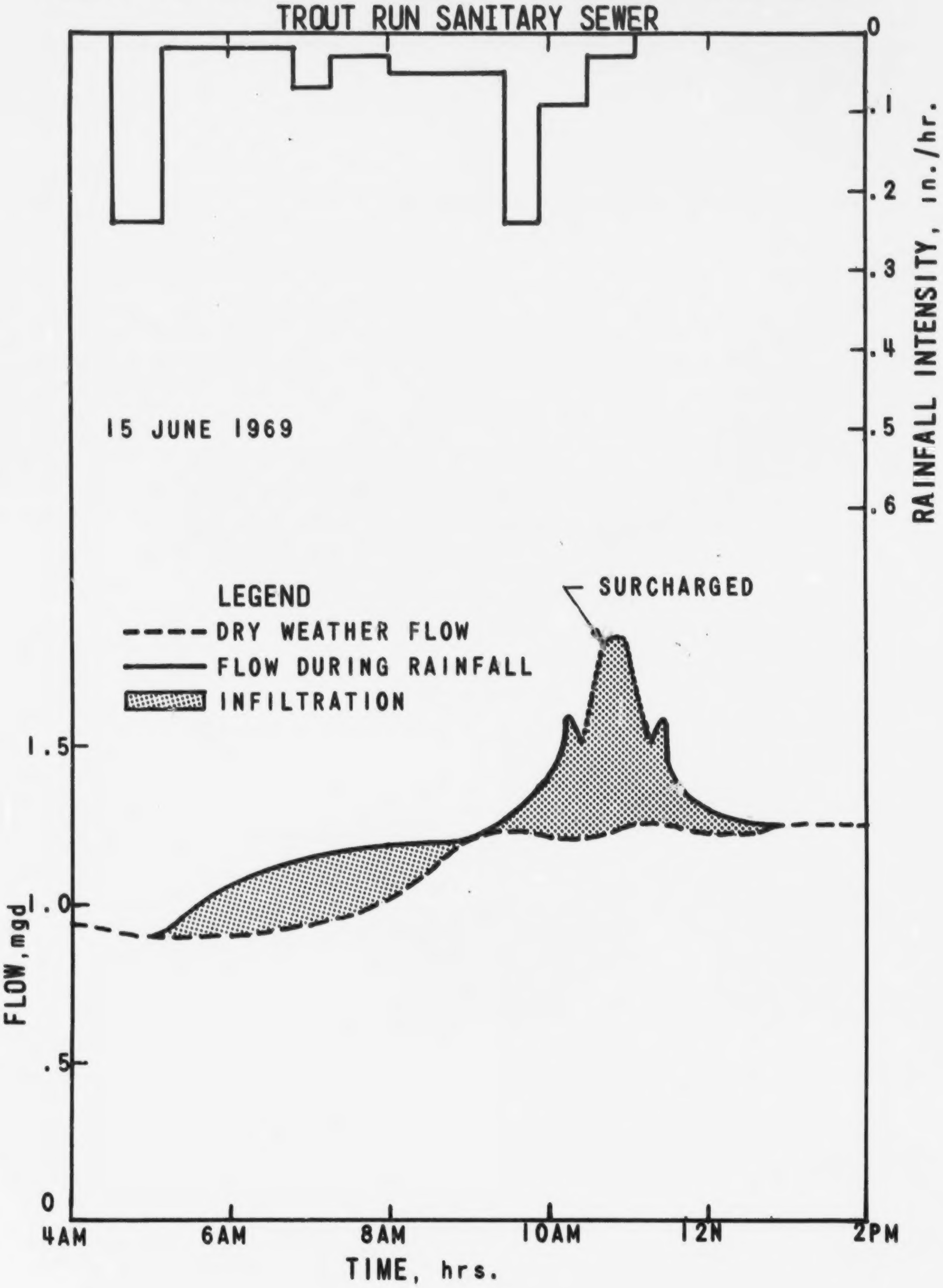


FIGURE 71 RAINFALL INTENSITY AND RATE OF DISCHARGE TROUT RUN SANITARY SEWER

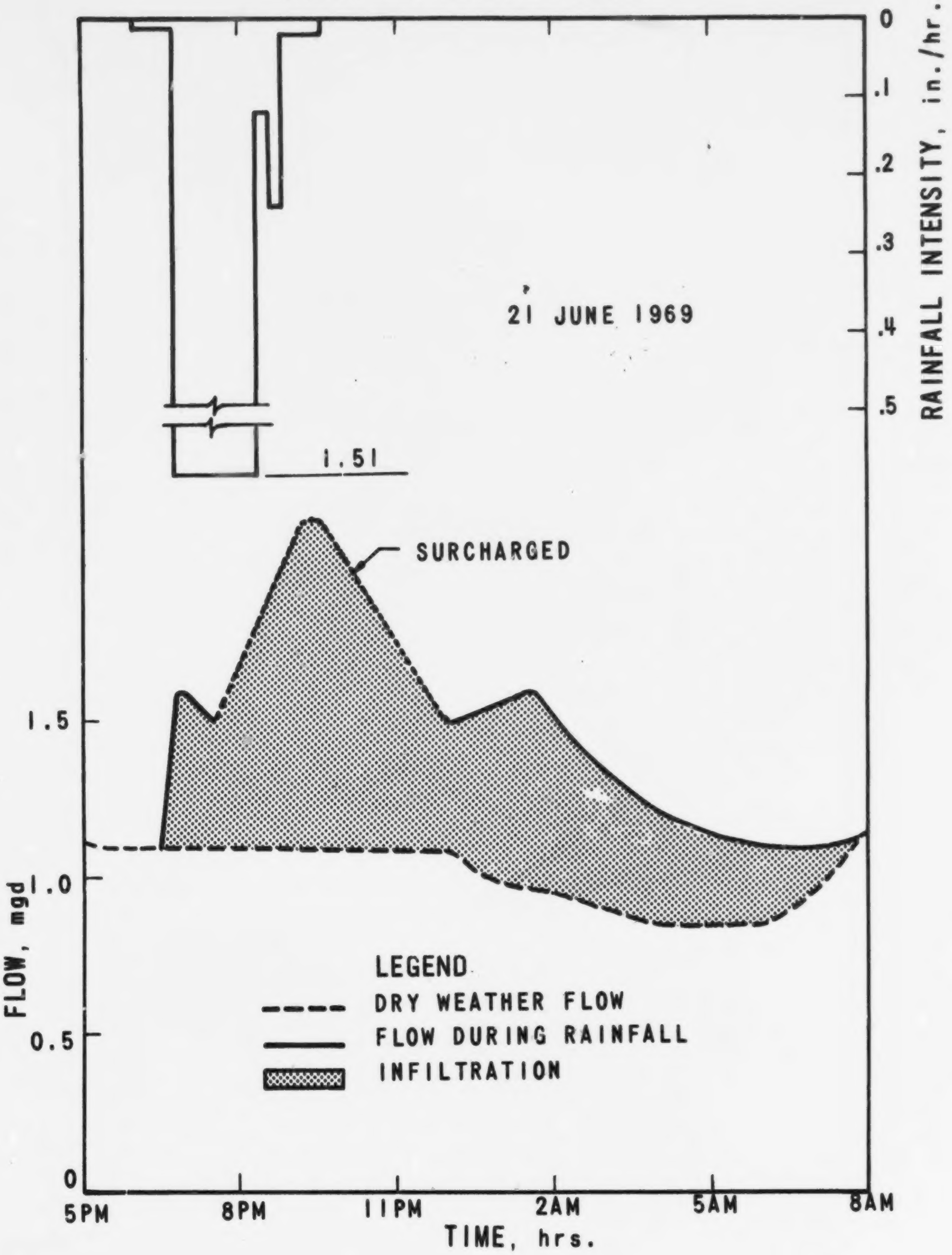


FIGURE 72 RAINFALL INTENSITY AND RATE OF DISCHARGE
TROUT RUN SANITARY SEWER

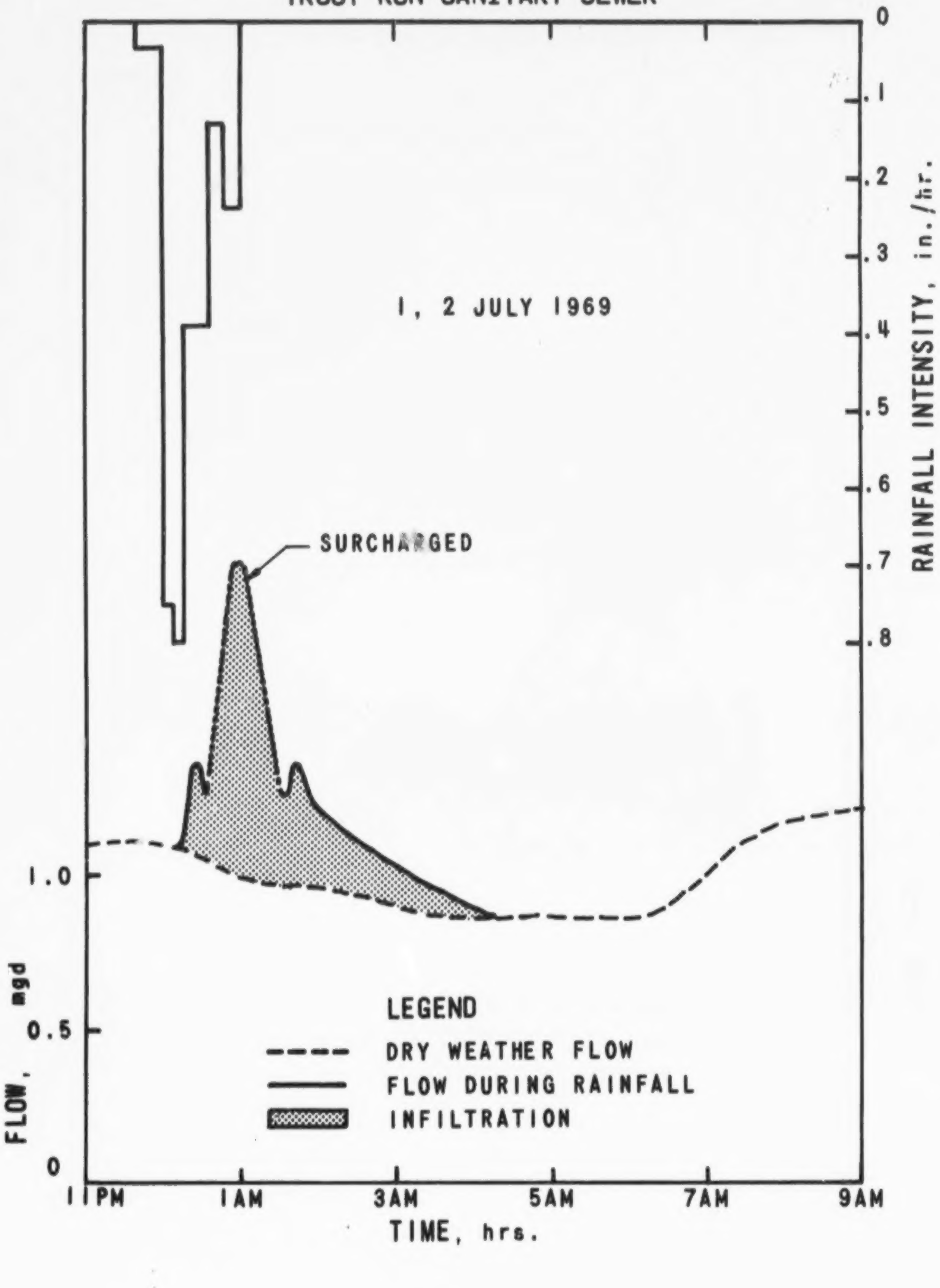


FIGURE 73 RAINFALL INTENSITY AND RATE OF DISCHARGE
TROUT RUN SANITARY SEWER

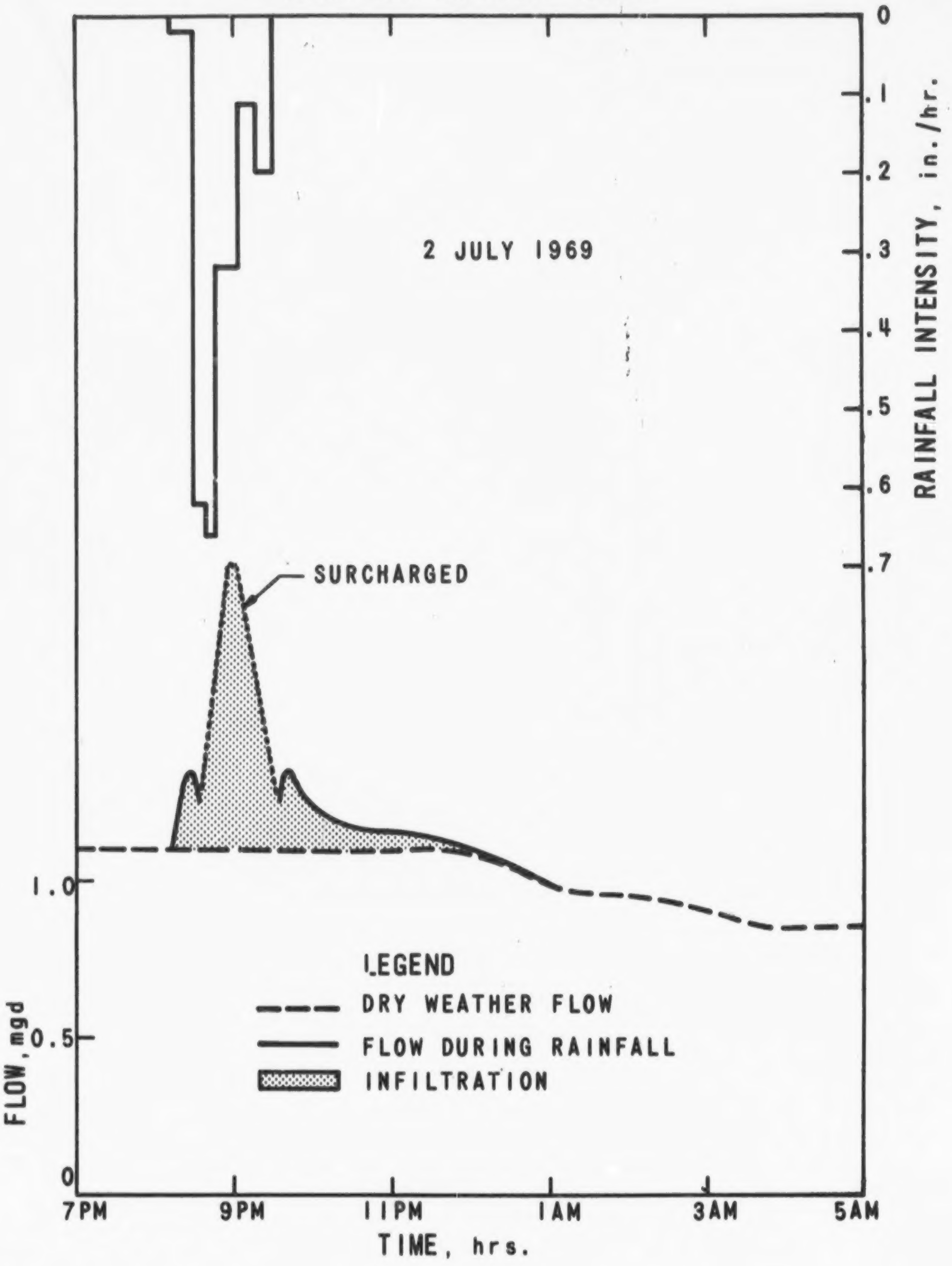


FIGURE 74 RAINFALL INTENSITY AND RATE OF DISCHARGE TROUT RUN SANITARY SEWER

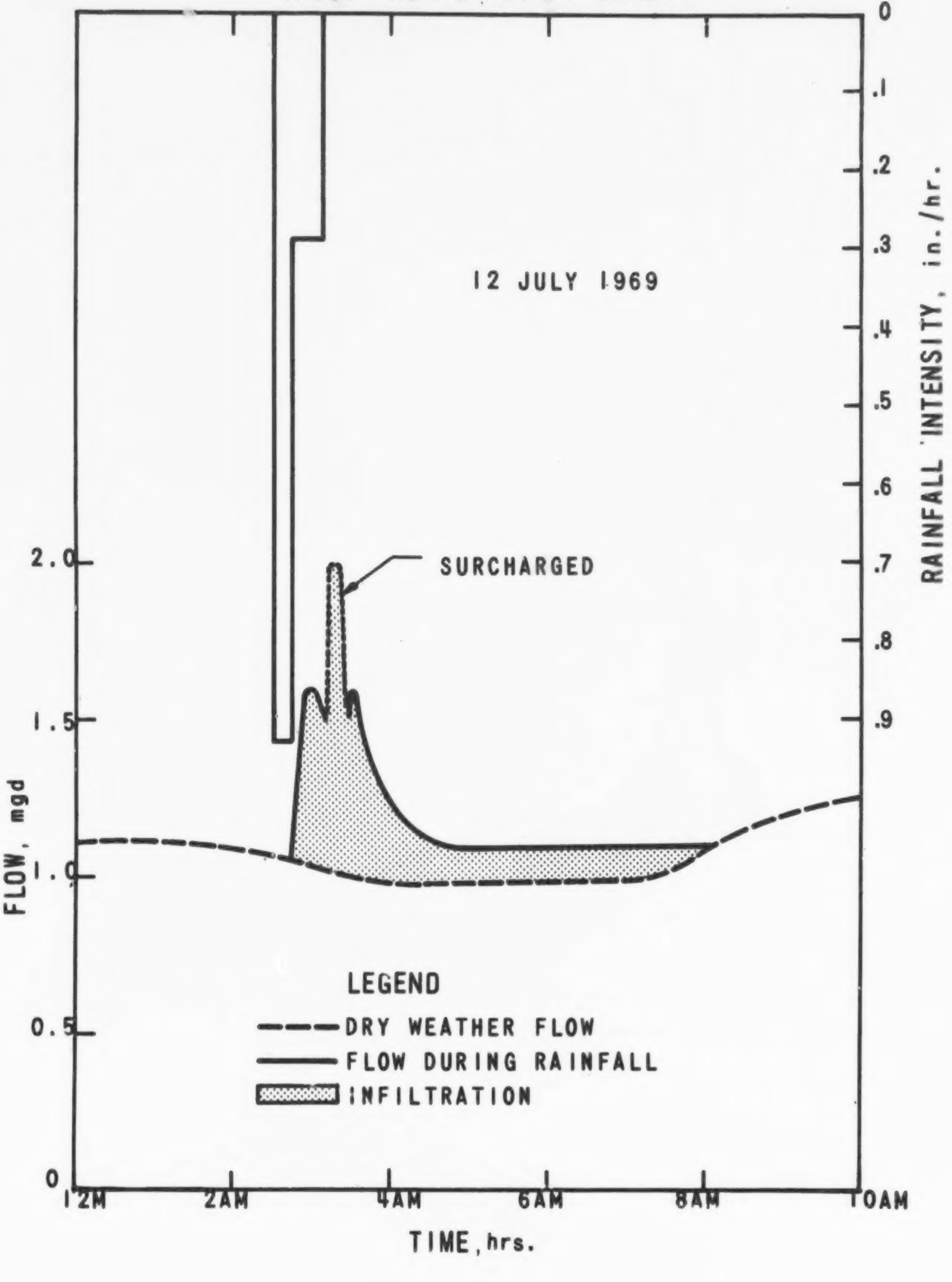


FIGURE 75 RAINFALL INTENSITY AND RATE OF DISCHARGE TROUT RUN SANITARY SEWER

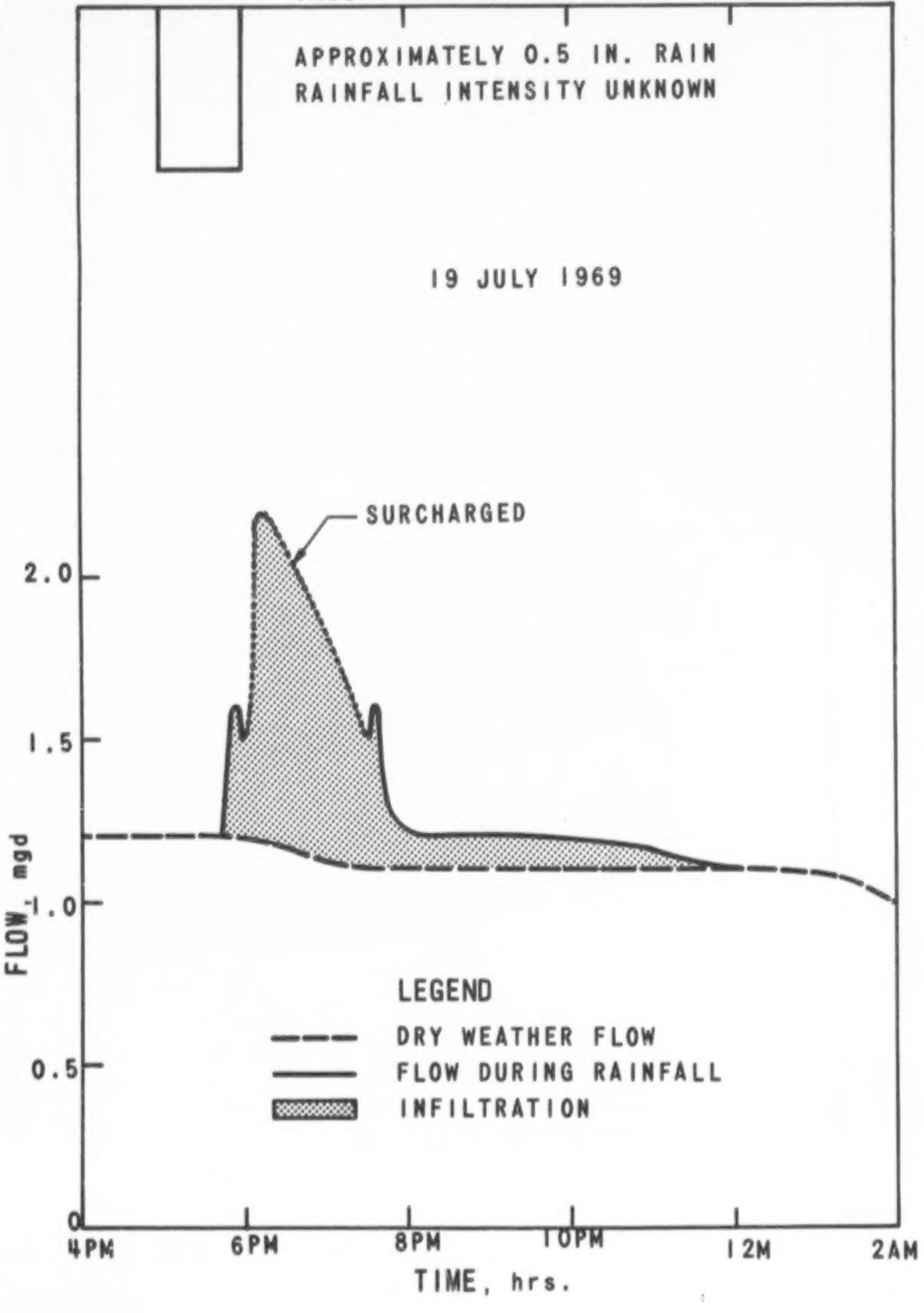


FIGURE 76 RAINFALL INTENSITY AND RATE OF DISCHARGE TROUT RUN SANITARY SEWER

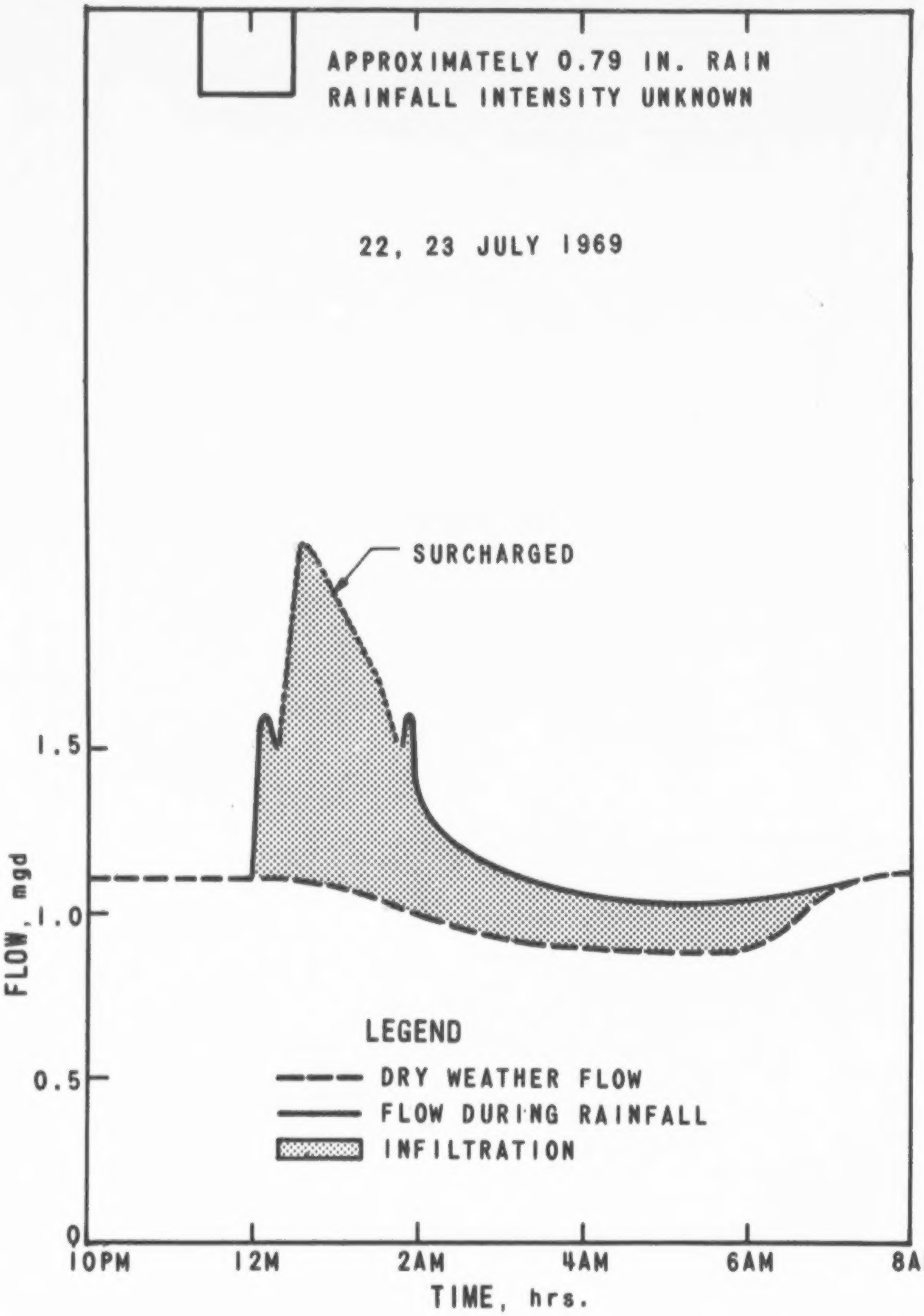


FIGURE 77 RAINFALL INTENSITY AND RATE OF DISCHARGE
TROUT RUN SANITARY SEWER

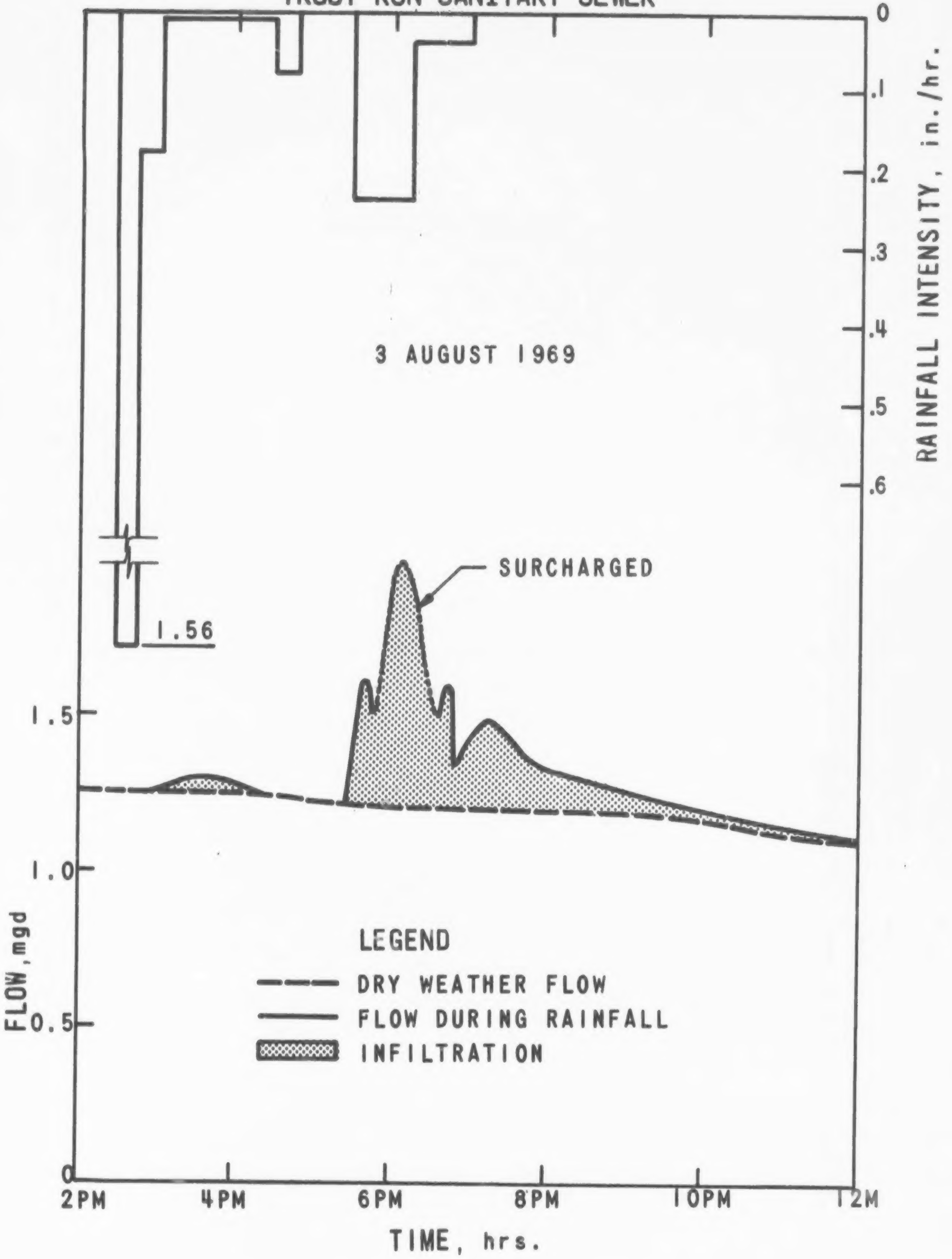


FIGURE 78 RAINFALL INTENSITY AND RATE OF DISCHARGE
24th STREET SANITARY SEWER

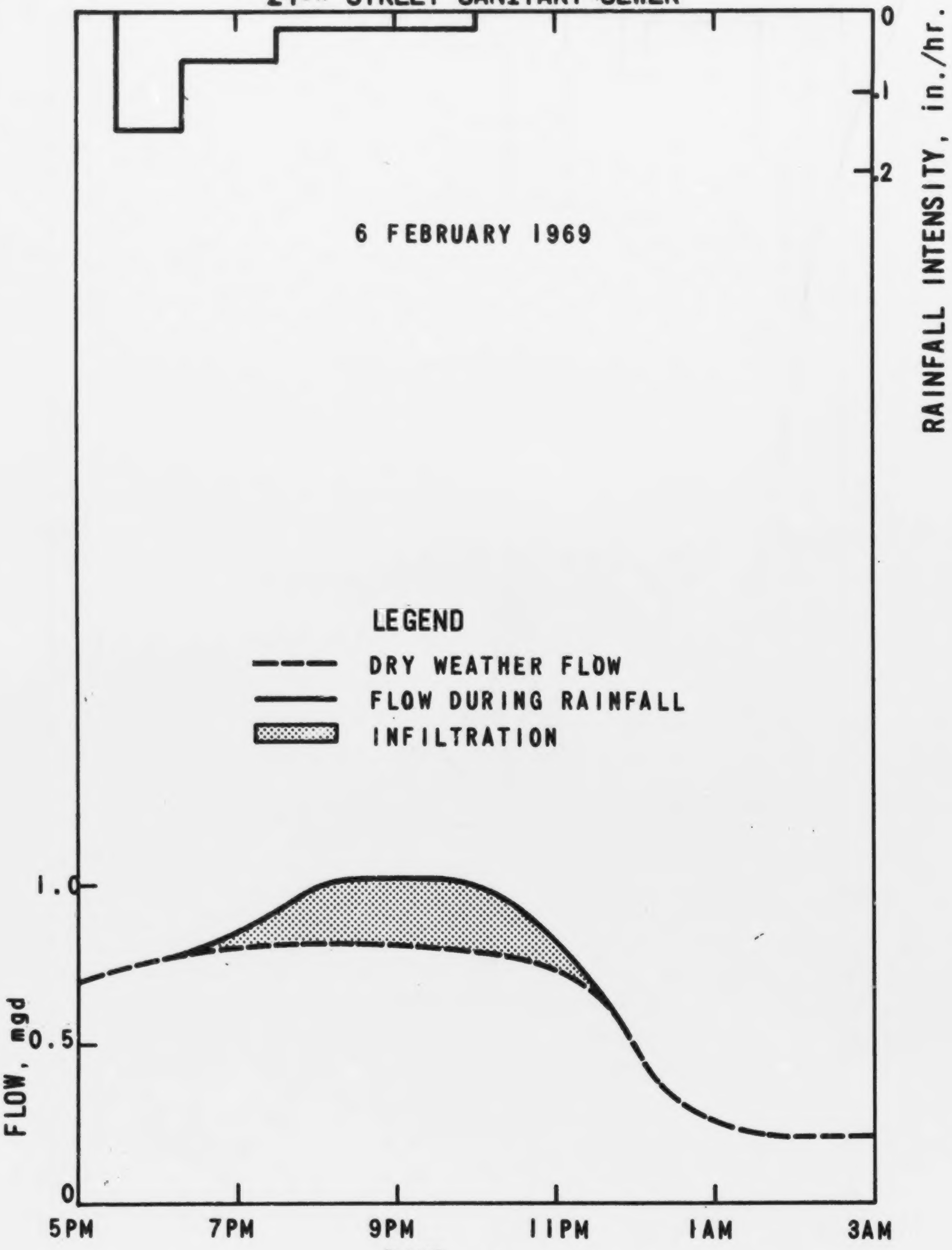


FIGURE 79 RAINFALL INTENSITY AND RATE OF DISCHARGE
24th STREET SANITARY SEWER

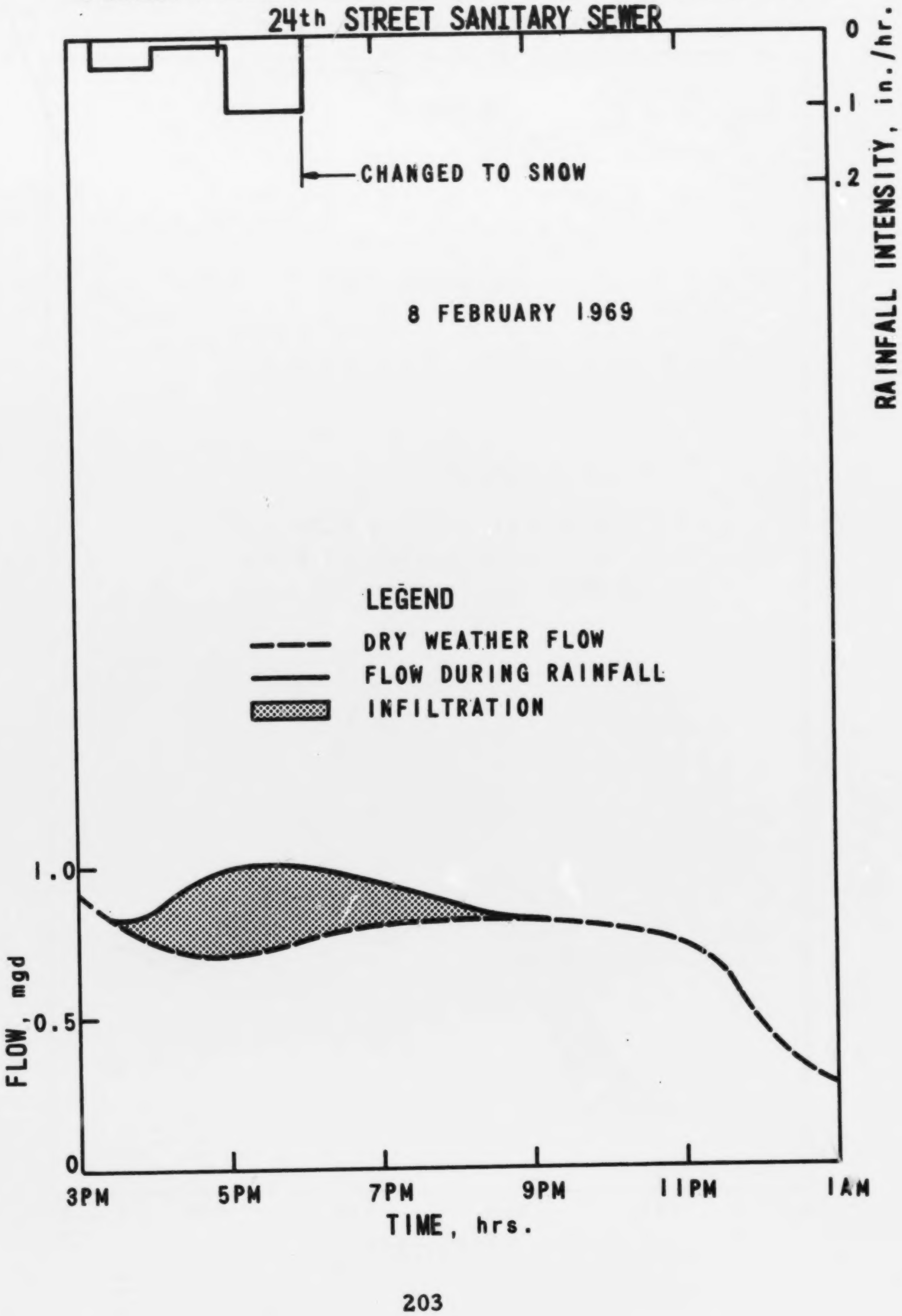


FIGURE 80 RAINFALL INTENSITY AND RATE OF DISCHARGE 24th STREET SANITARY SEWER

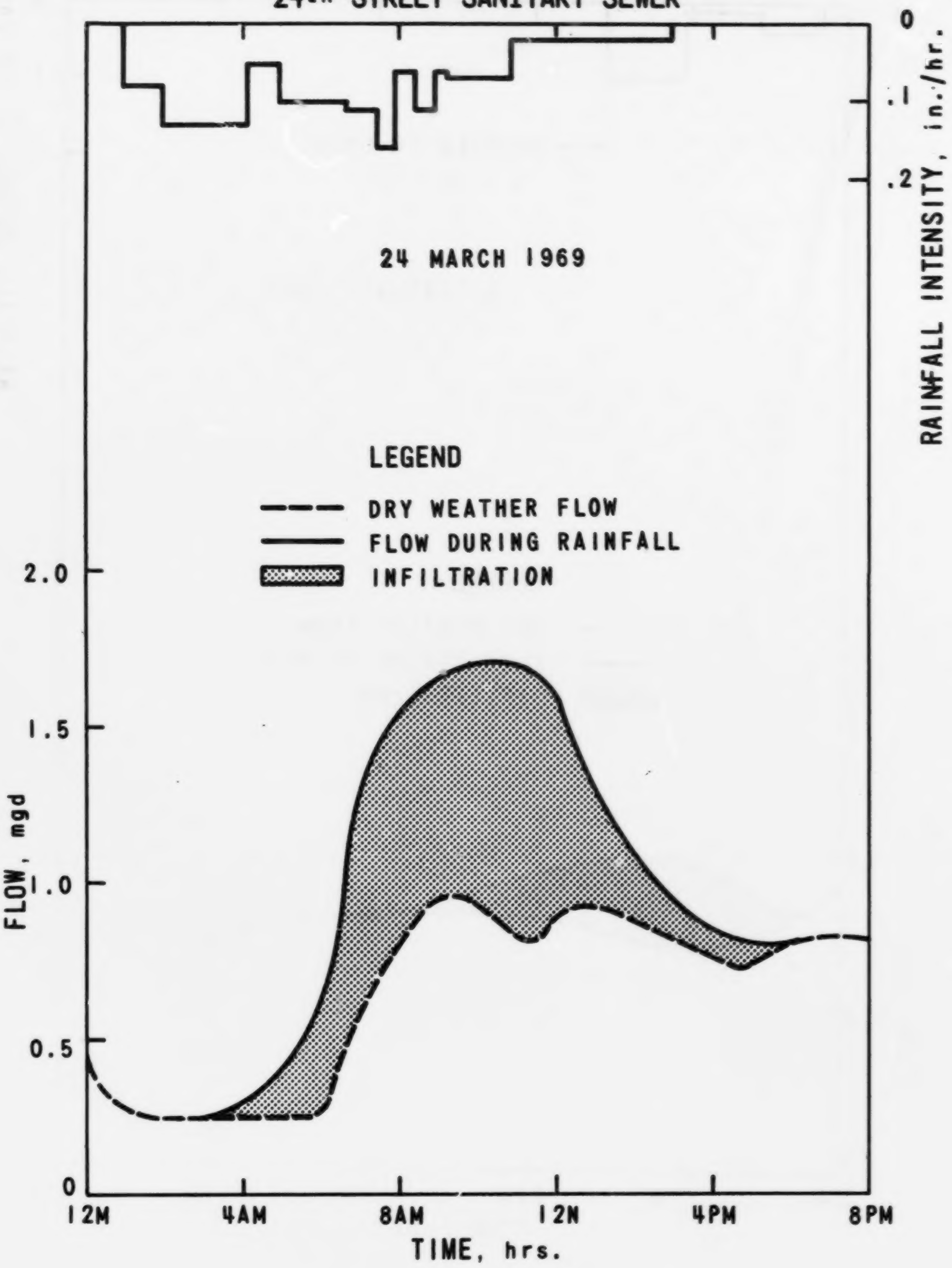


FIGURE 81 RAINFALL INTENSITY AND RATE OF DISCHARGE
24th STREET SANITARY SEWER

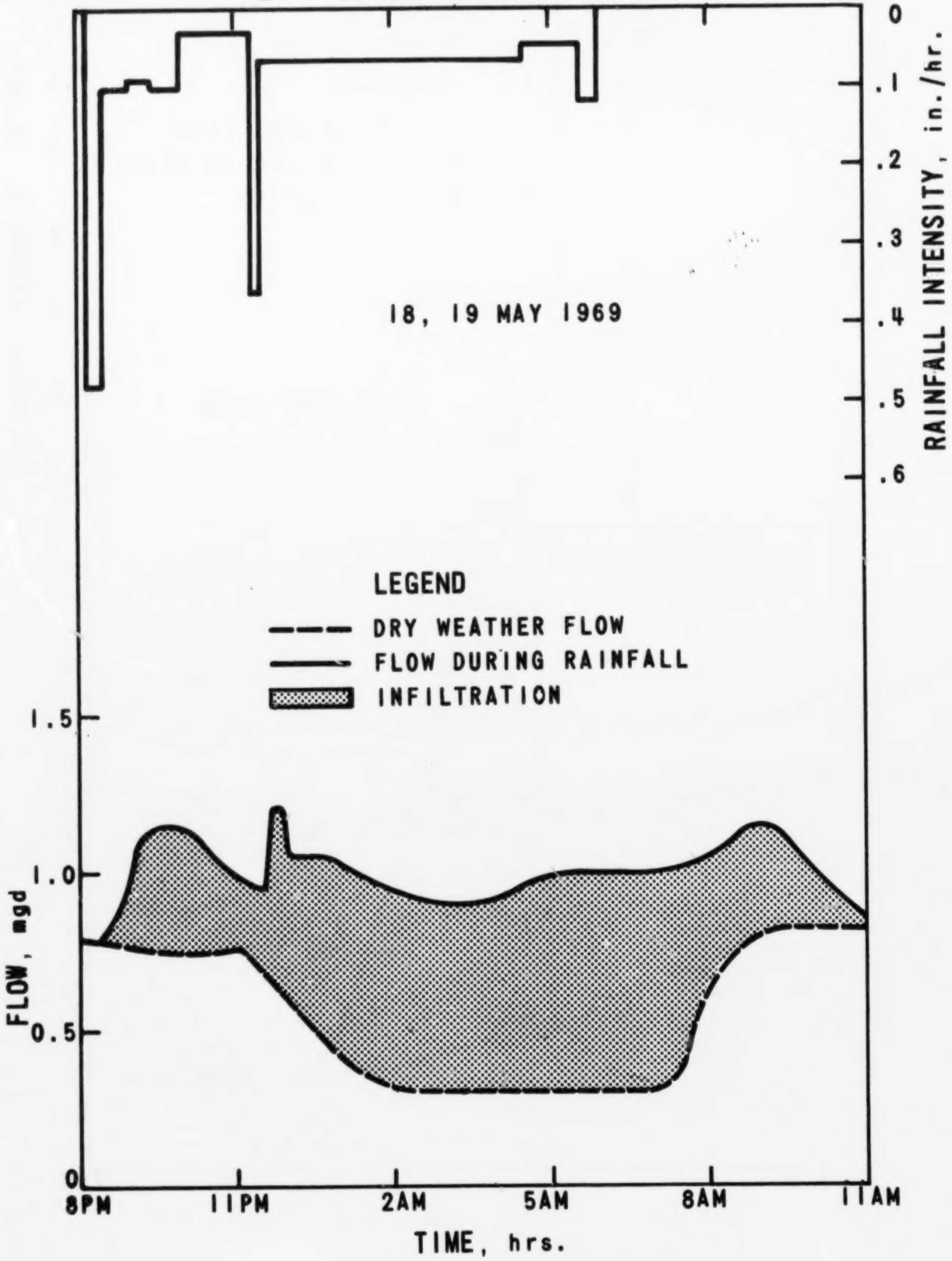


FIGURE 82 RAINFALL INTENSITY AND RATE OF DISCHARGE 24th STREET SANITARY SEWER

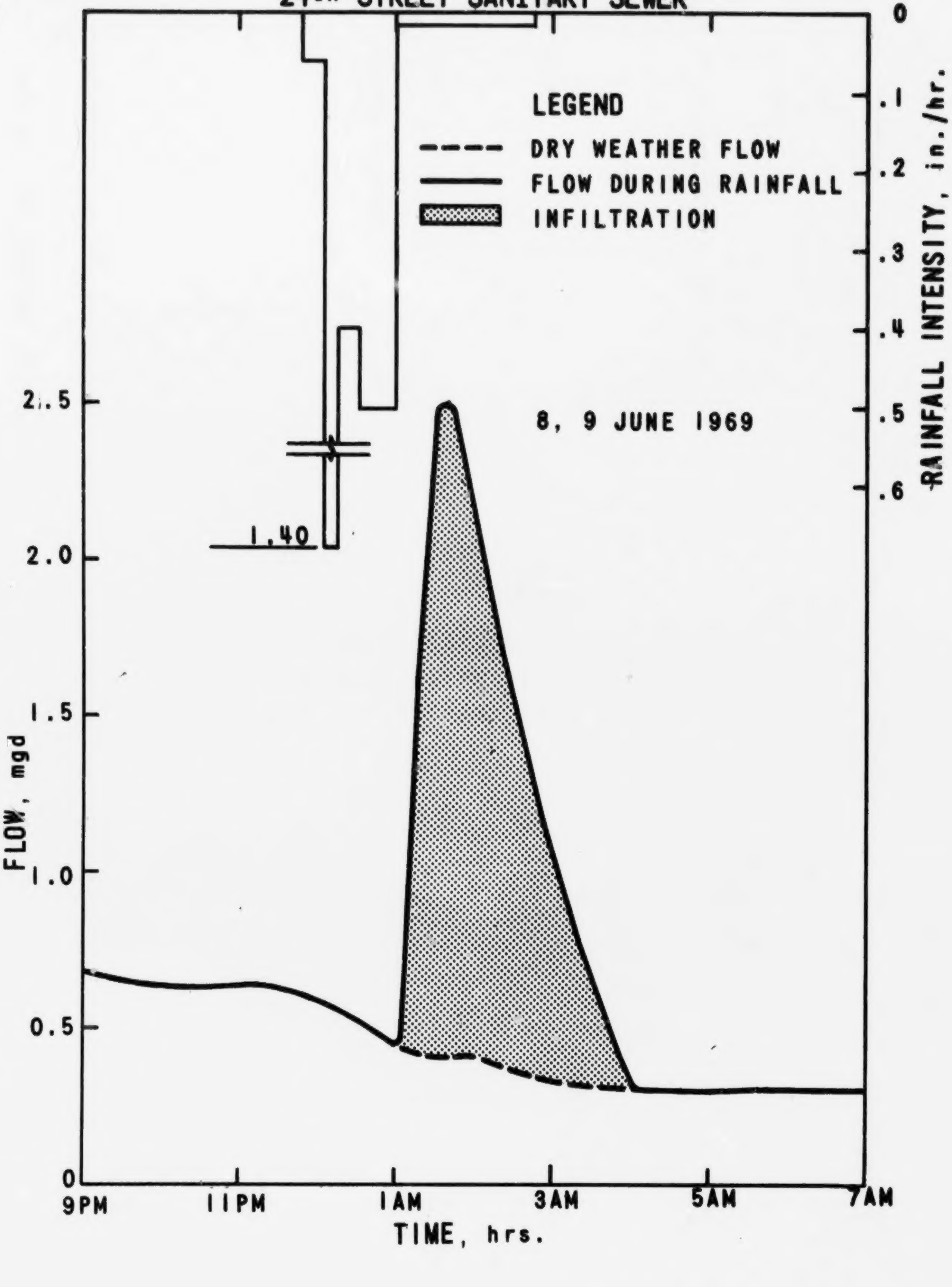


FIGURE 83 RAINFALL INTENSITY AND RATE OF DISCHARGE
24th STREET SANITARY SEWER

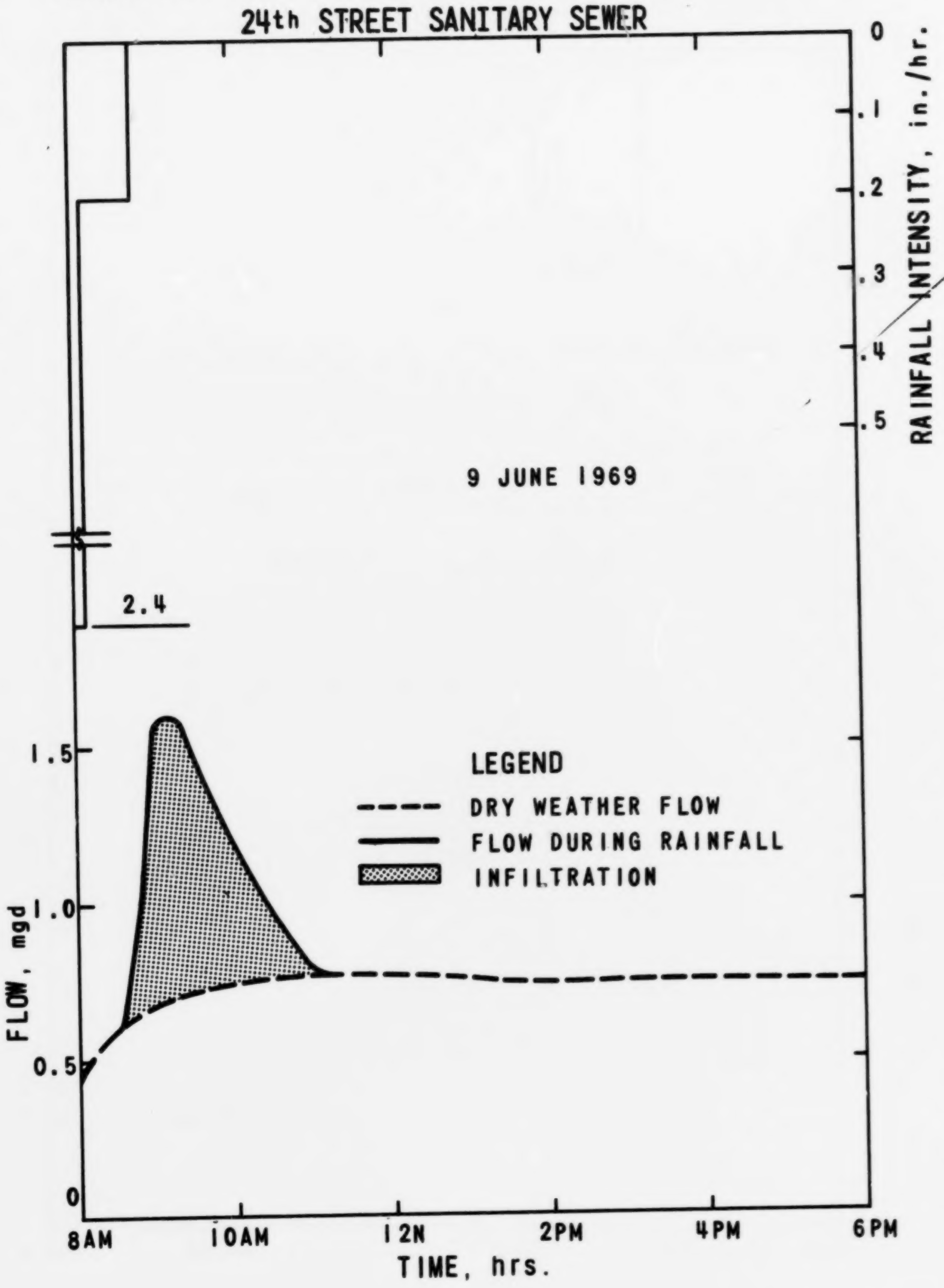


FIGURE 84 RAINFALL INTENSITY AND RATE OF DISCHARGE
24th STREET SANITARY SEWER

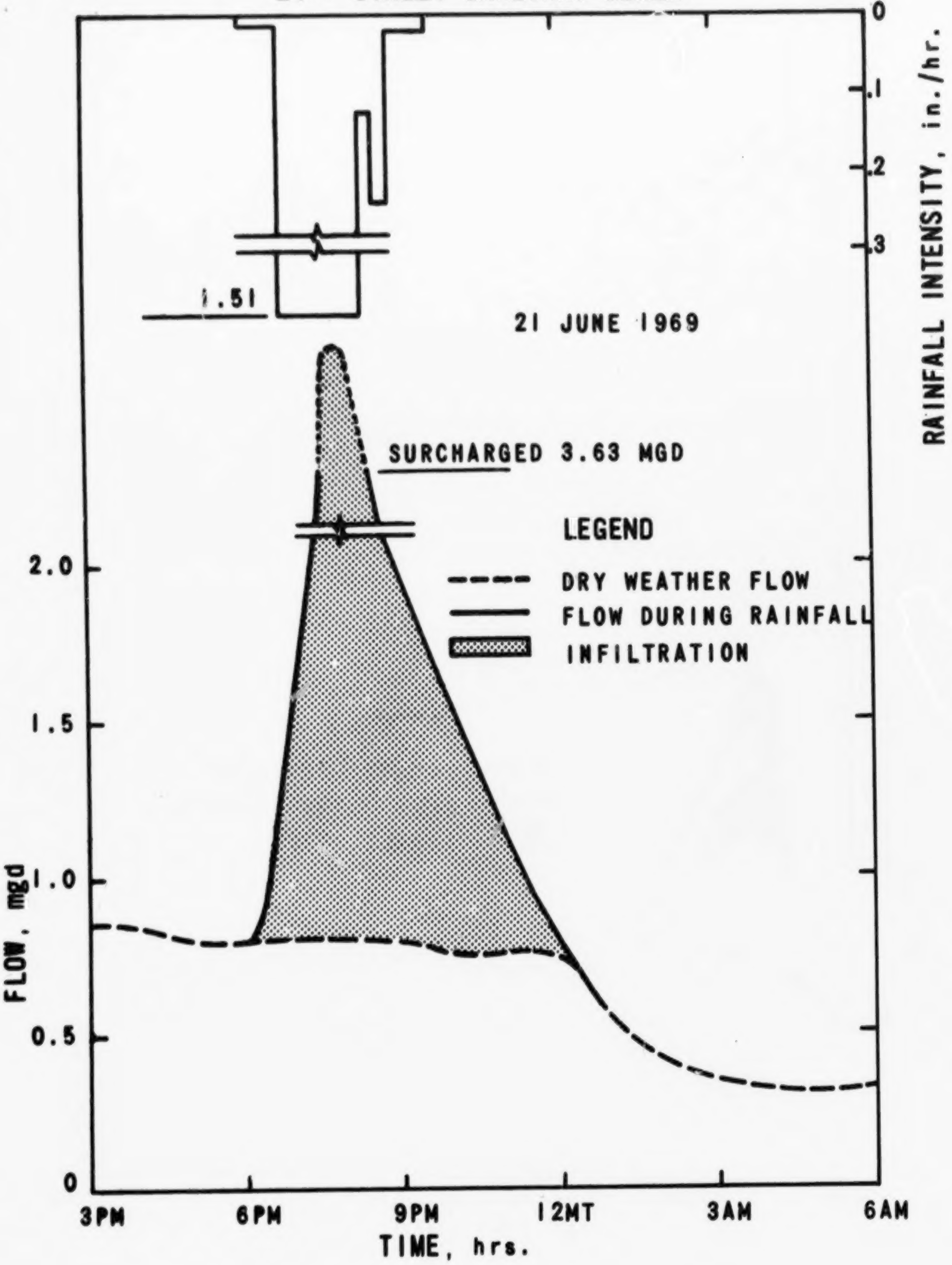


FIGURE 85 RAINFALL INTENSITY AND RATE OF DISCHARGE
24th STREET SANITARY SEWER

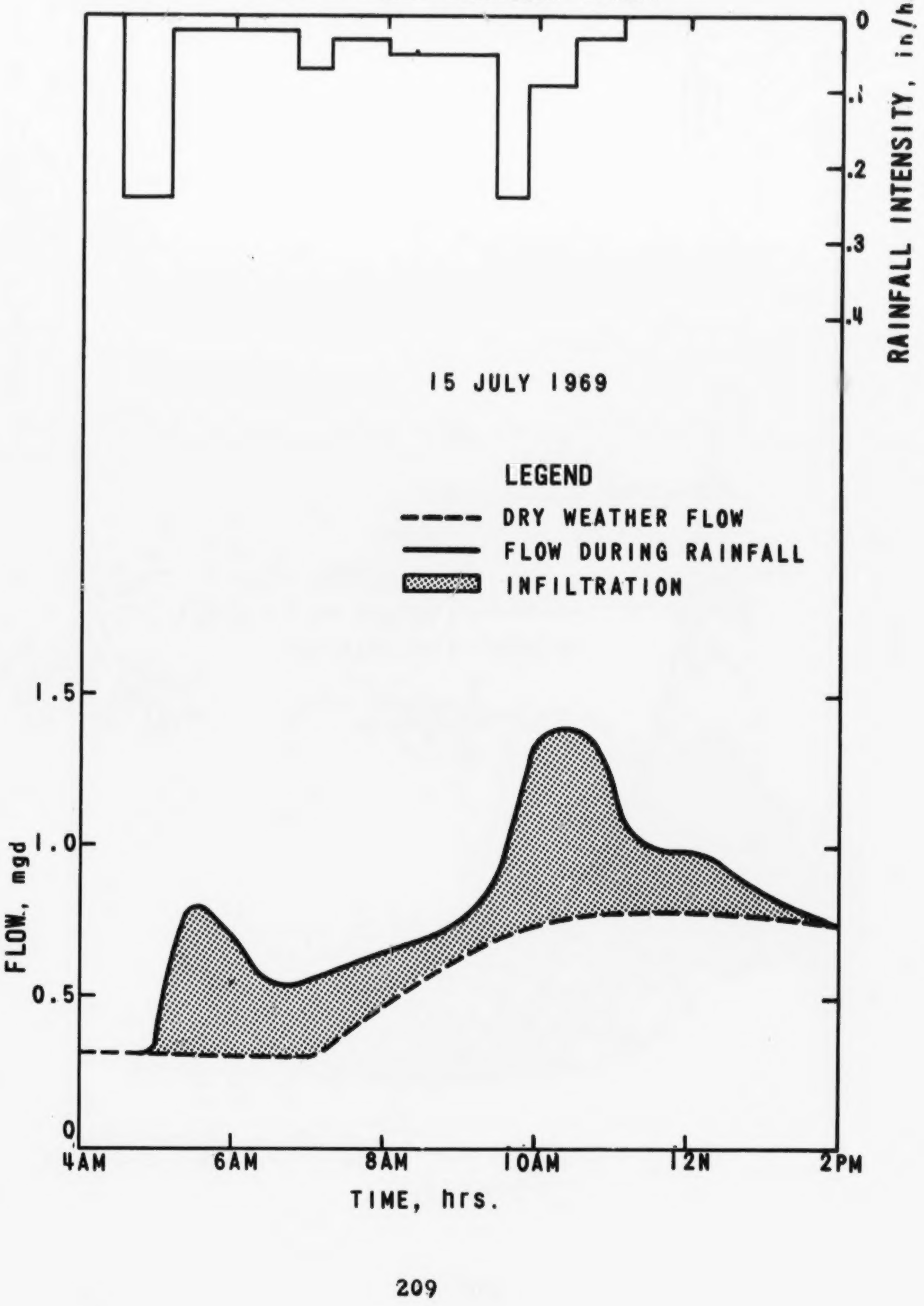


FIGURE 86 RAINFALL INTENSITY AND RATE OF DISCHARGE
24th STREET SANITARY SEWER

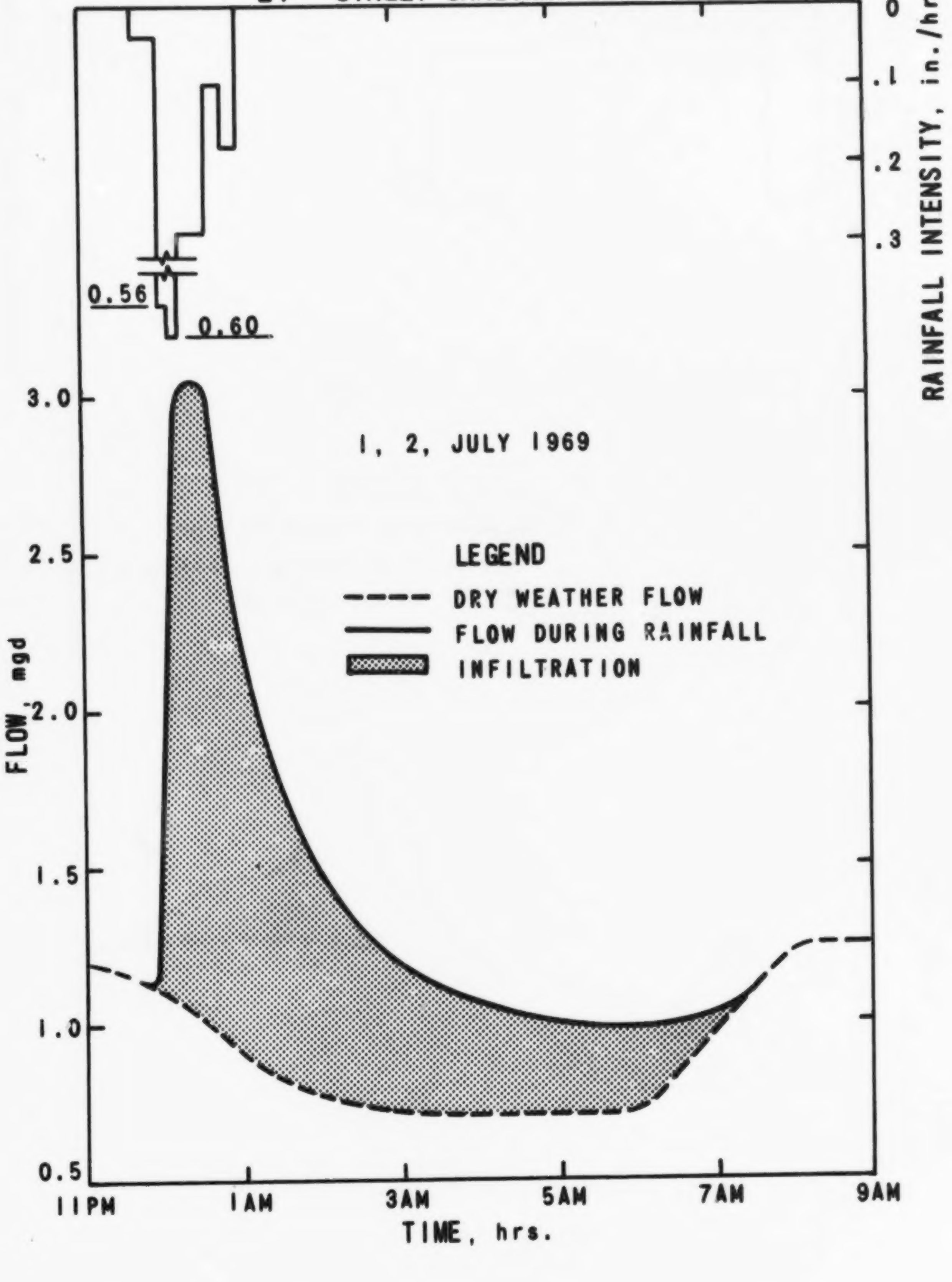


FIGURE 87 RAINFALL INTENSITY AND RATE OF DISCHARGE
24th STREET SANITARY SEWER

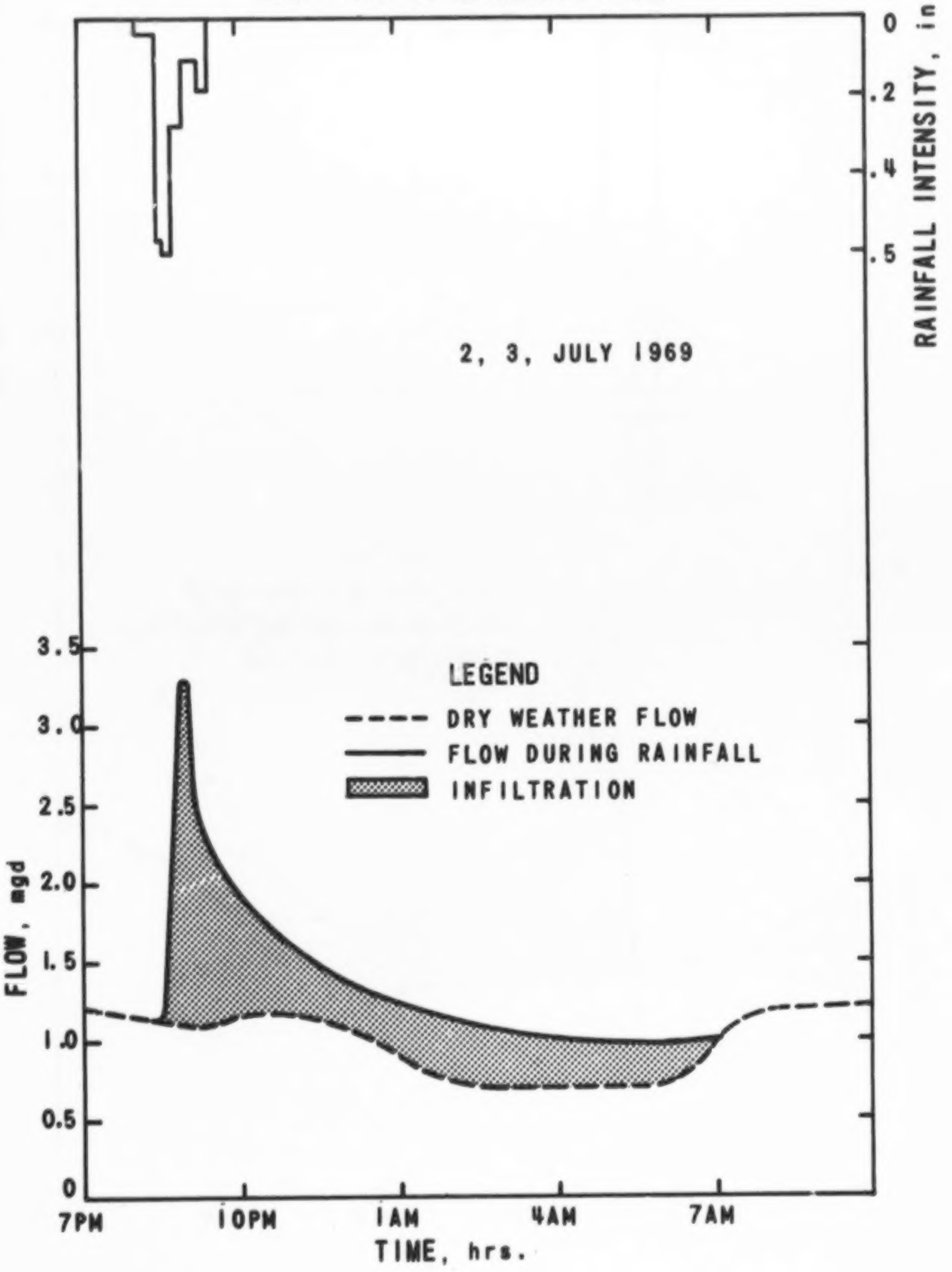


FIGURE 88 RAINFALL INTENSITY AND RATE OF DISCHARGE
24th STREET SANITARY SEWER

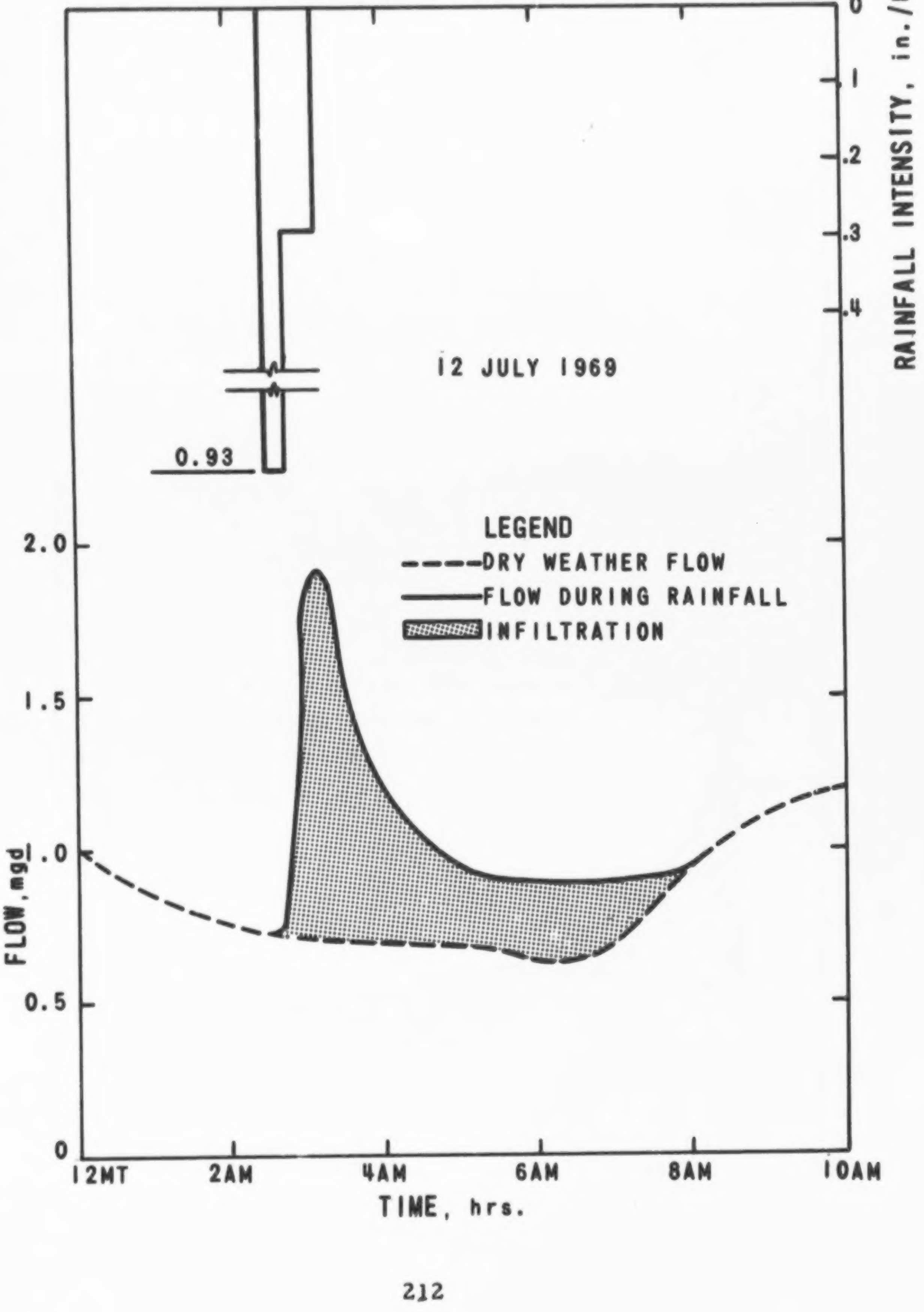


FIGURE 89 RAINFALL AND RATE OF OVERFLOW
WATER POLLUTION CONTROL PLANT

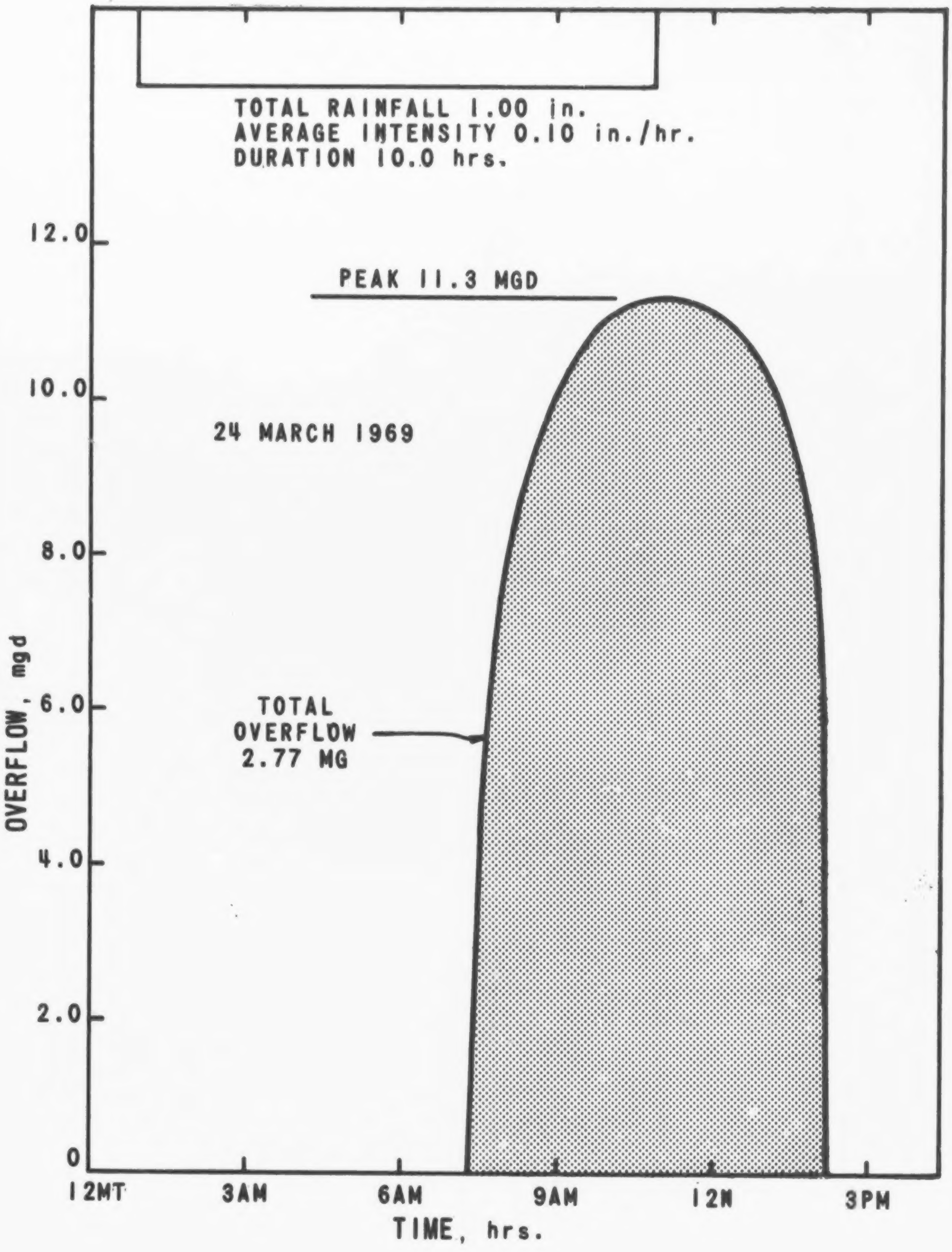


FIGURE 90 RAINFALL AND RATE OF OVERFLOW
WATER POLLUTION CONTROL PLANT

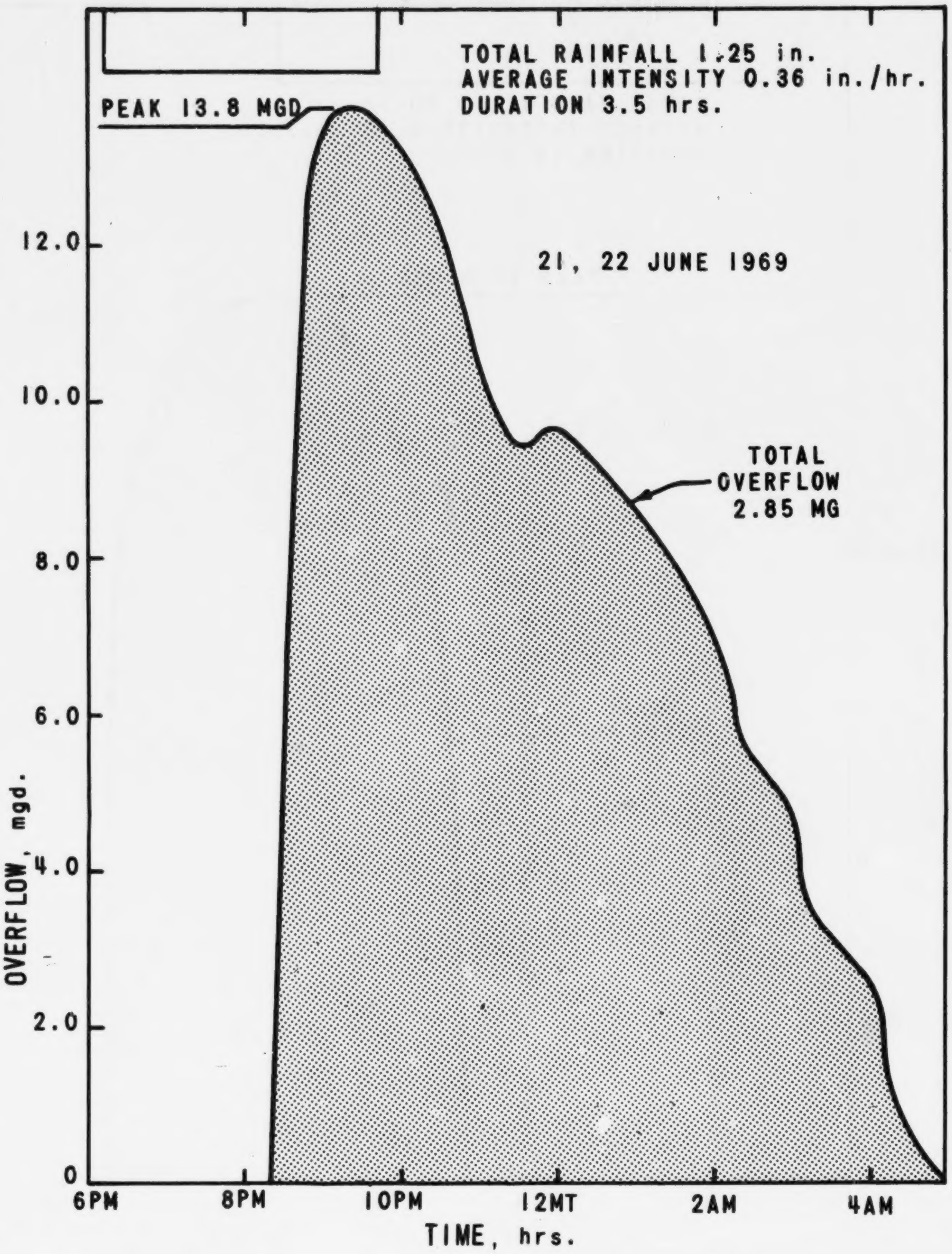


FIGURE 91 RAINFALL AND RATE OF OVERFLOW
WATER POLLUTION CONTROL PLANT

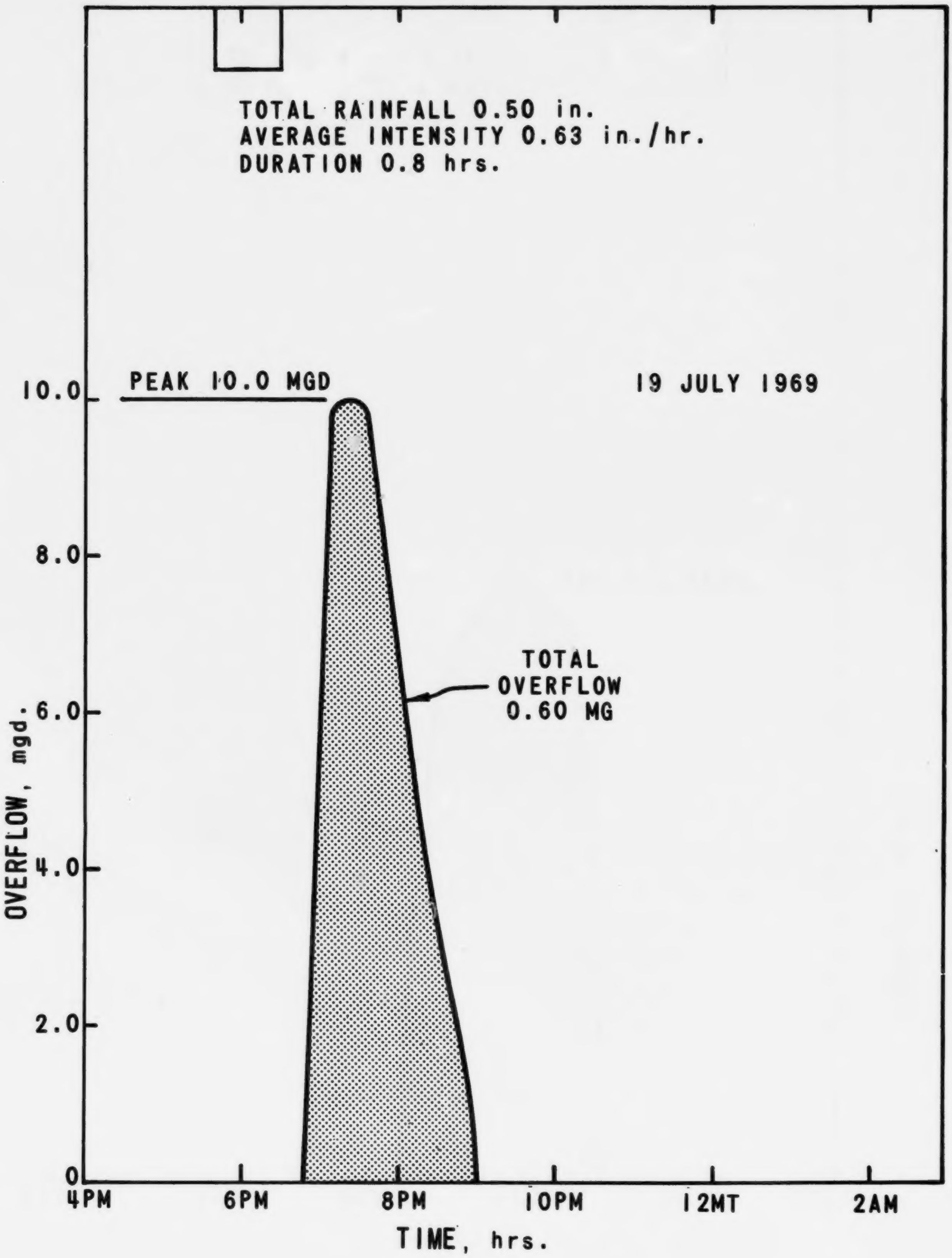


FIGURE 92 RAINFALL AND RATE OF OVERFLOW
WATER POLLUTION CONTROL PLANT

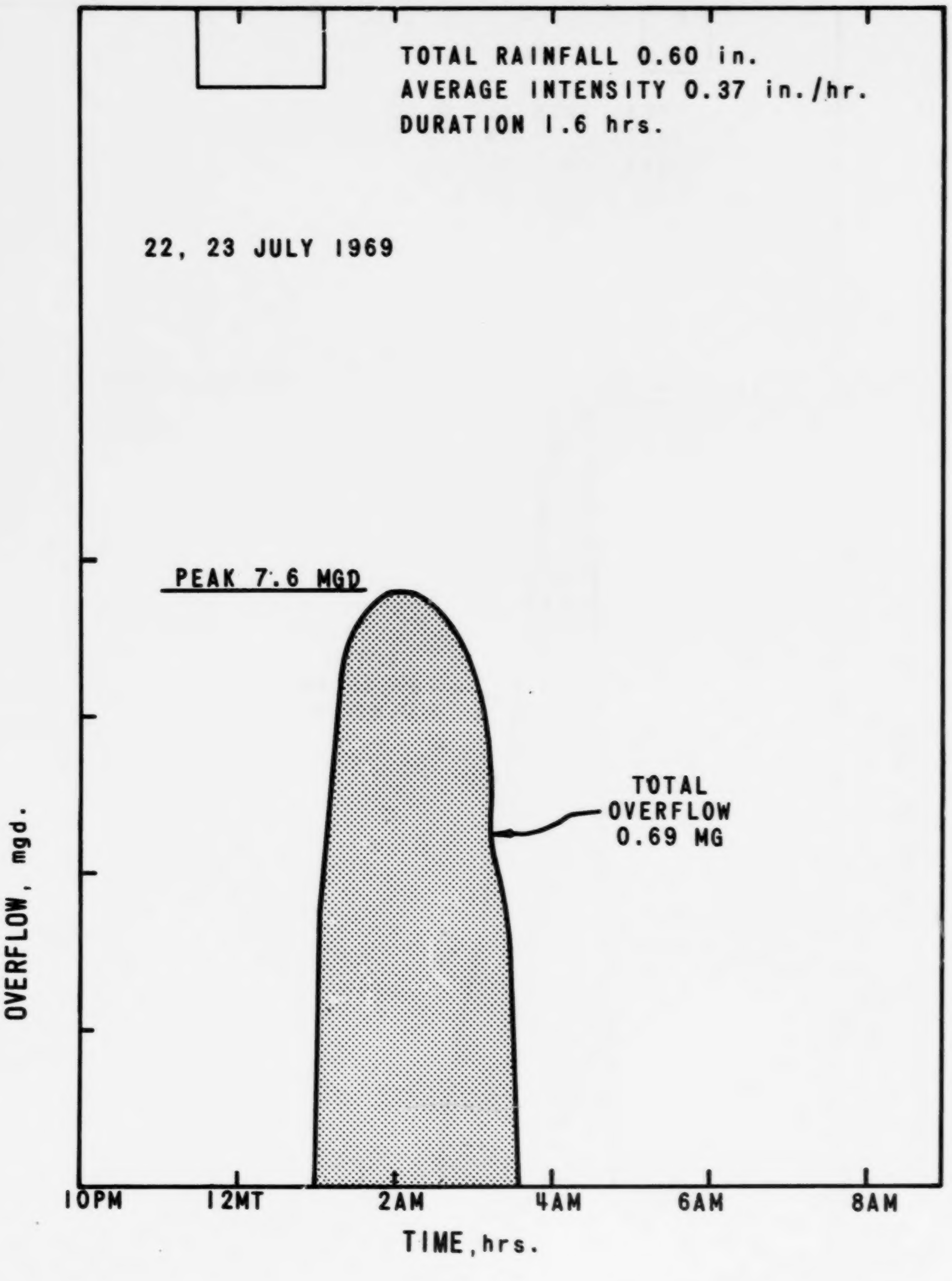
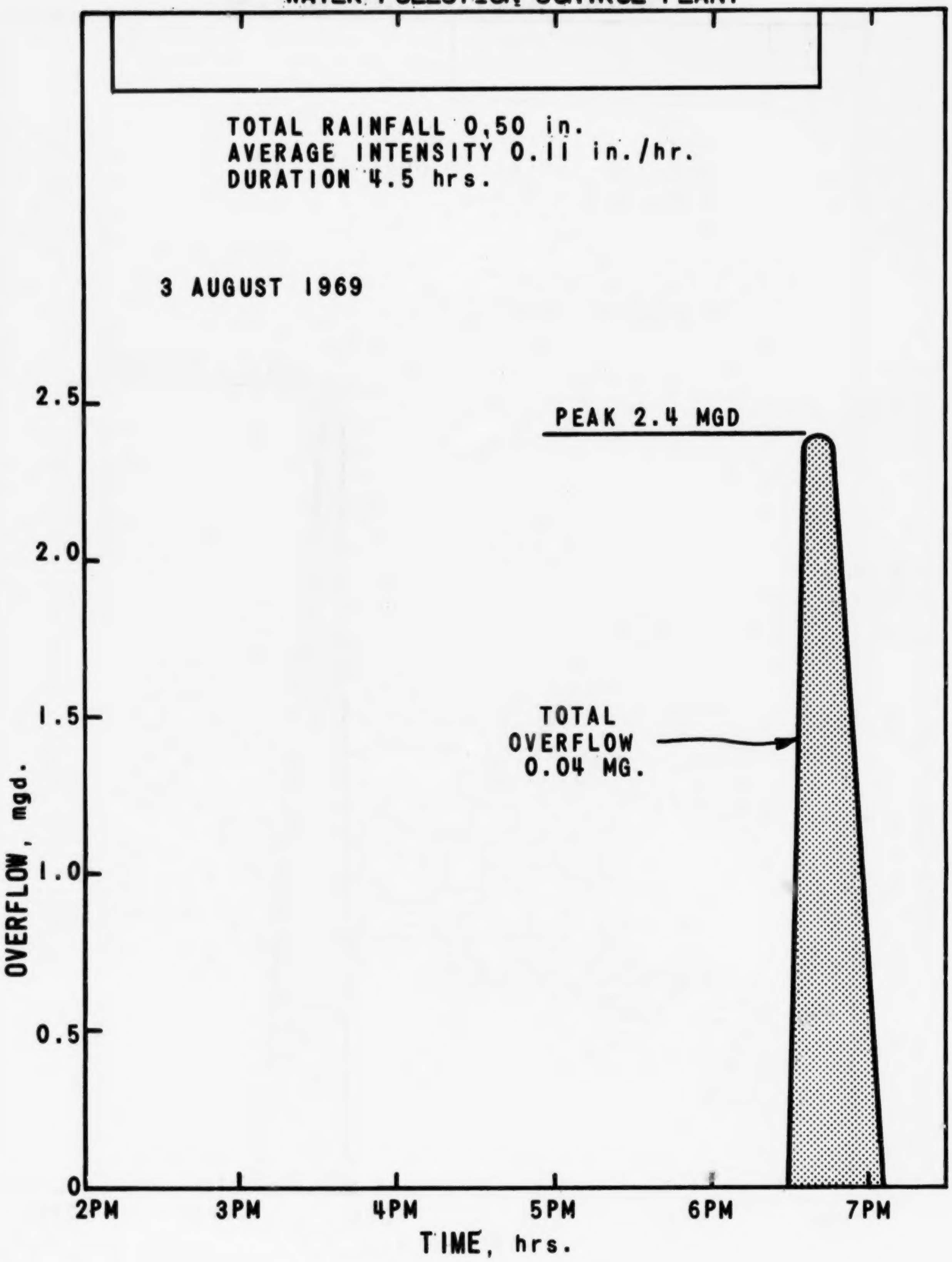


FIGURE 93 RAINFALL AND RATE OF OVERFLOW
WATER POLLUTION CONTROL PLANT



TOTAL RAINFALL 0,50 in.
AVERAGE INTENSITY 0.11 in./hr.
DURATION 4.5 hrs.

3 AUGUST 1969

PEAK 2.4 MGD

TOTAL OVERFLOW 0.04 MG.

FIGURE 94 RAINFALL AND RATE OF OVERFLOW
WATER POLLUTION CONTROL PLANT

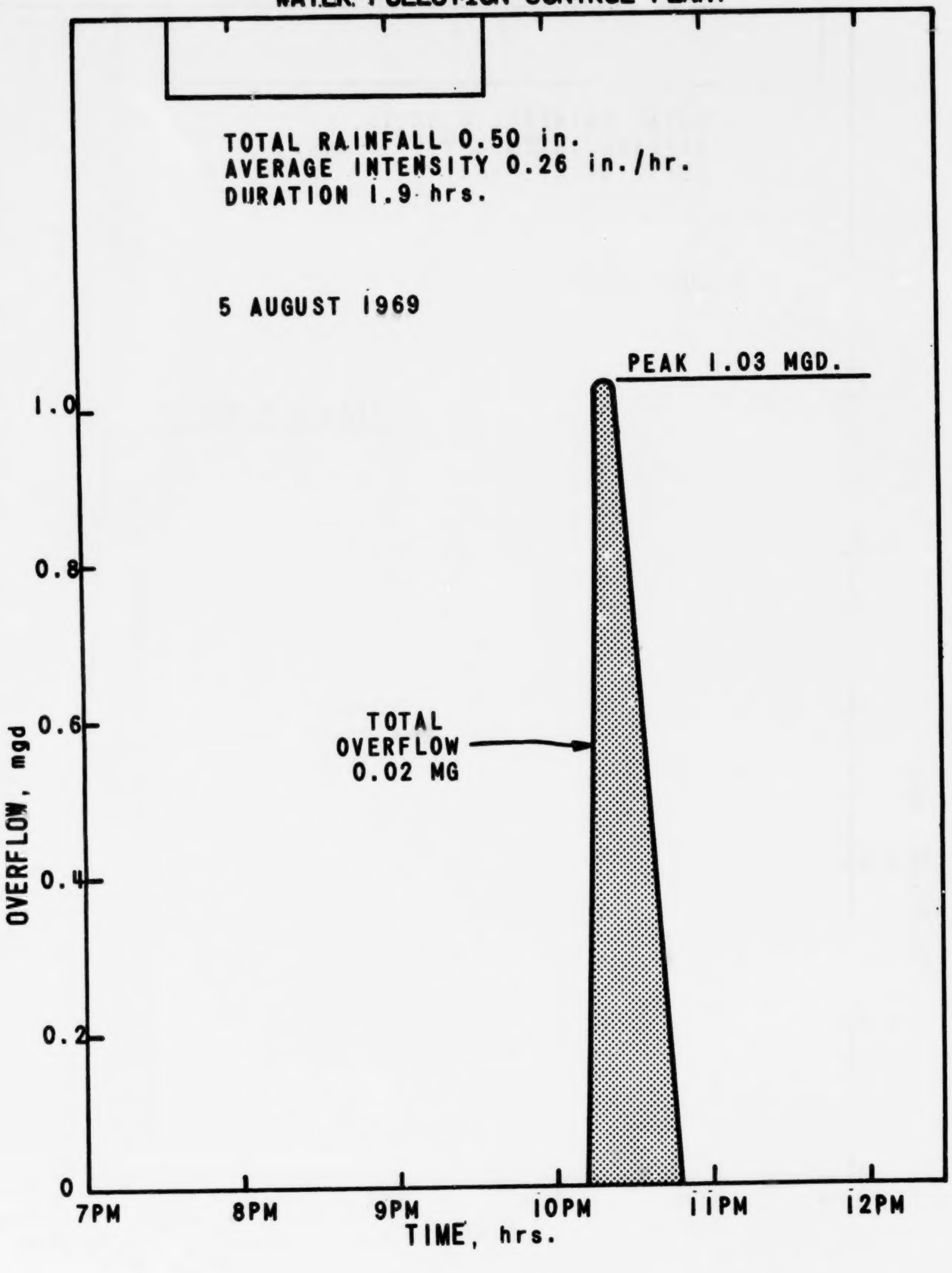


FIGURE 95 STAGE-DISCHARGE CURVE
MURRAY RUN STREAM

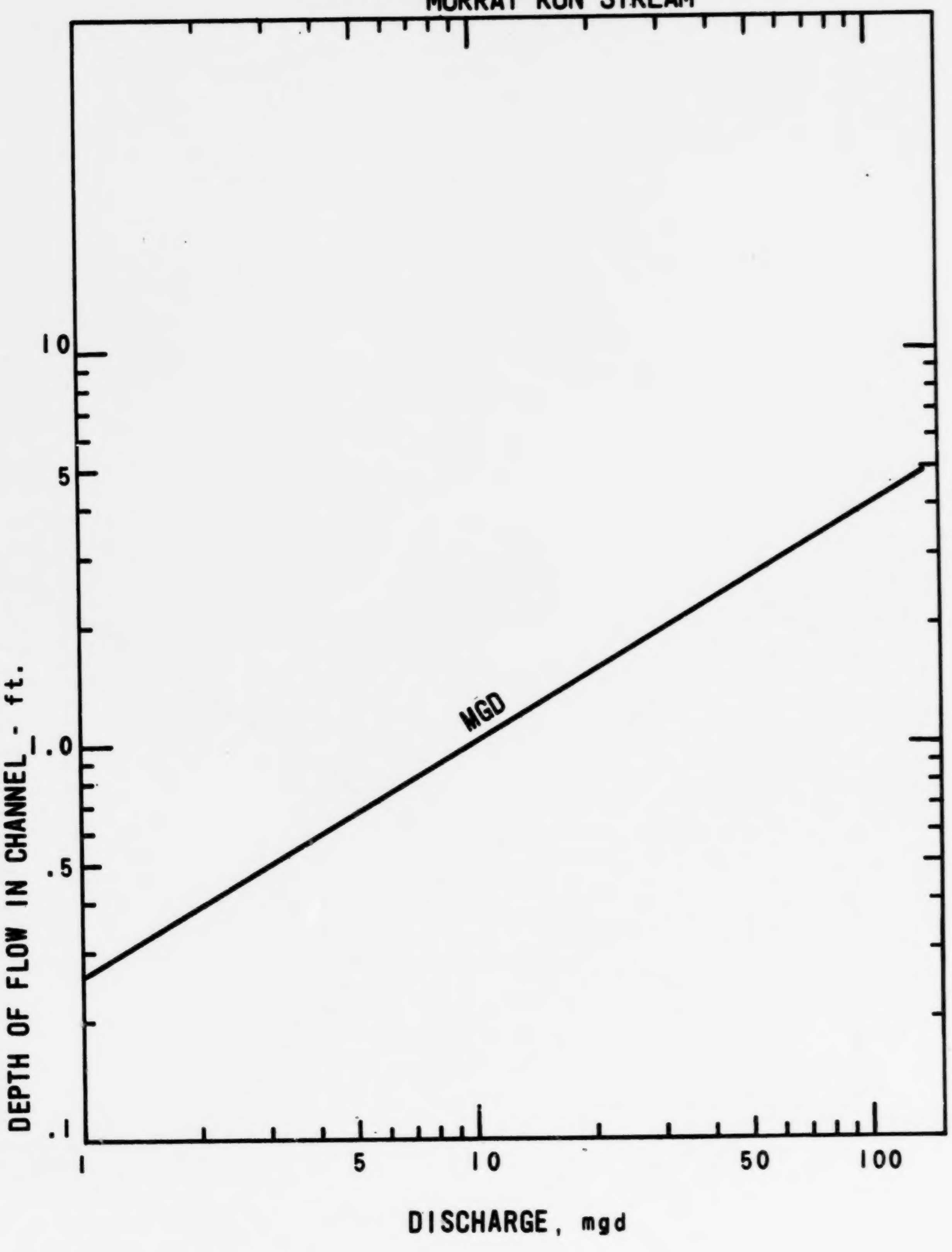


FIGURE 96 STAGE-DISCHARGE CURVE
TROUT RUN STREAM

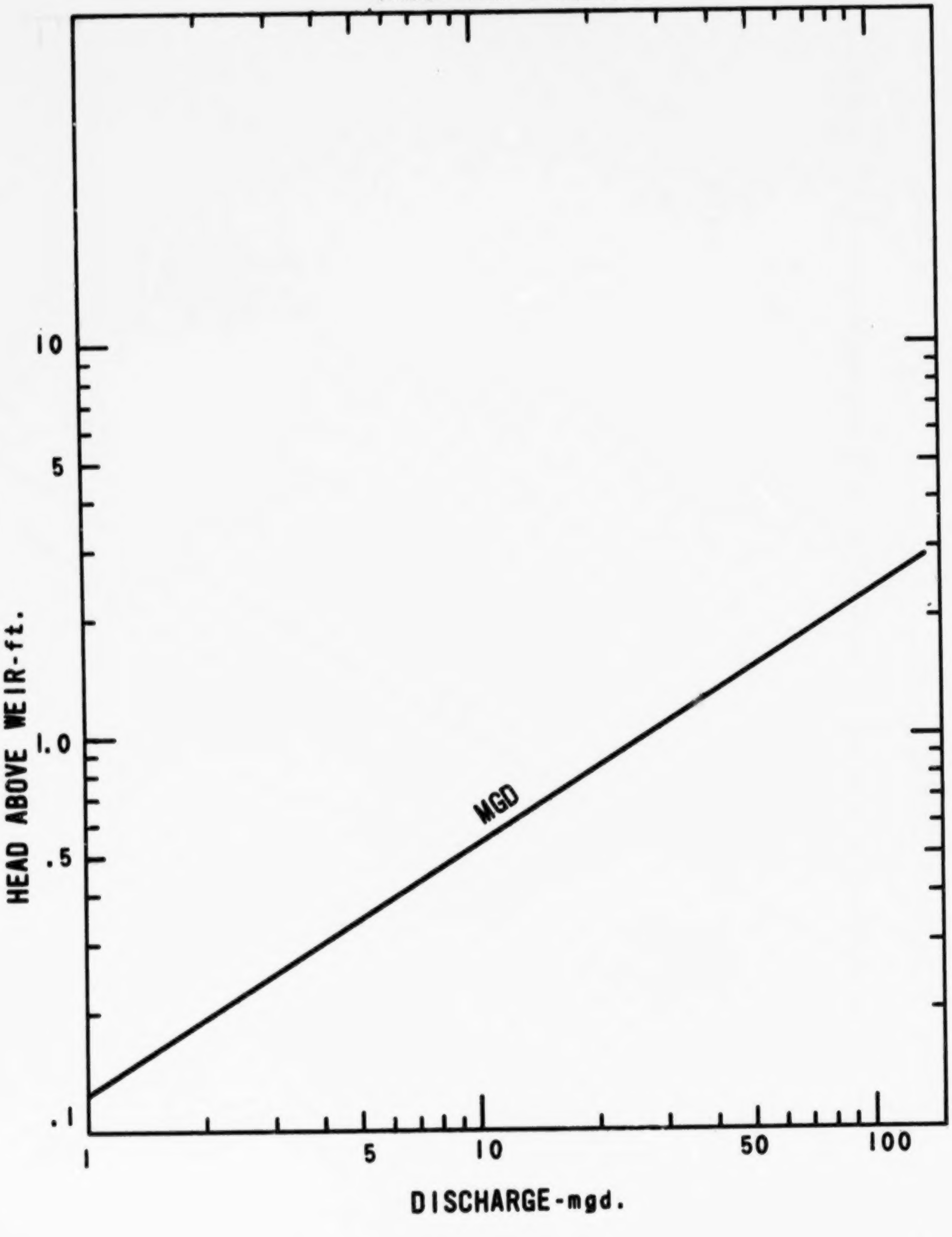


FIGURE 97 STAGE-DISCHARGE CURVE
24th STREET STREAM

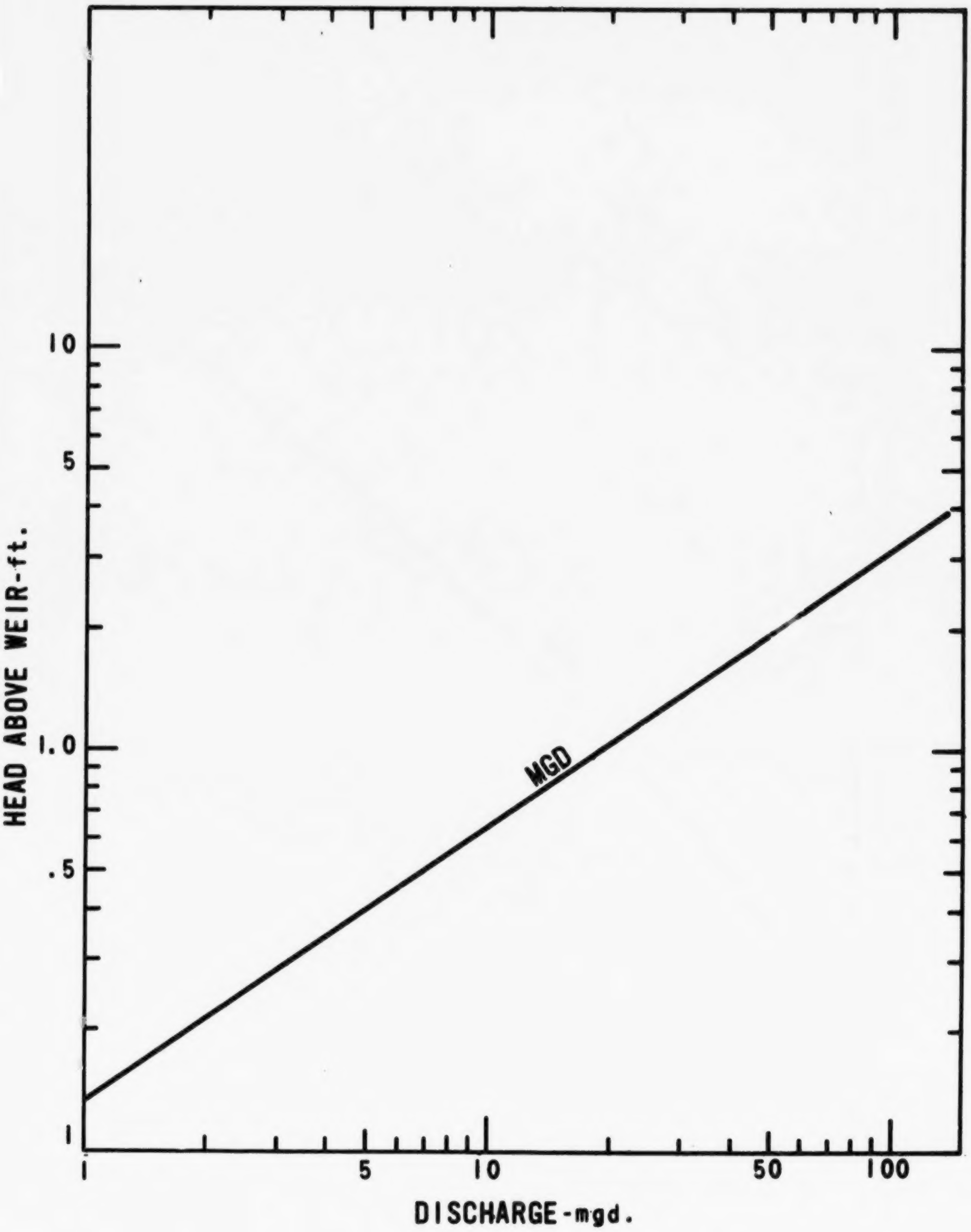


FIGURE 98 STAGE - DISCHARGE CURVE
WEIR IN MURRAY RUN SANITARY SEWER

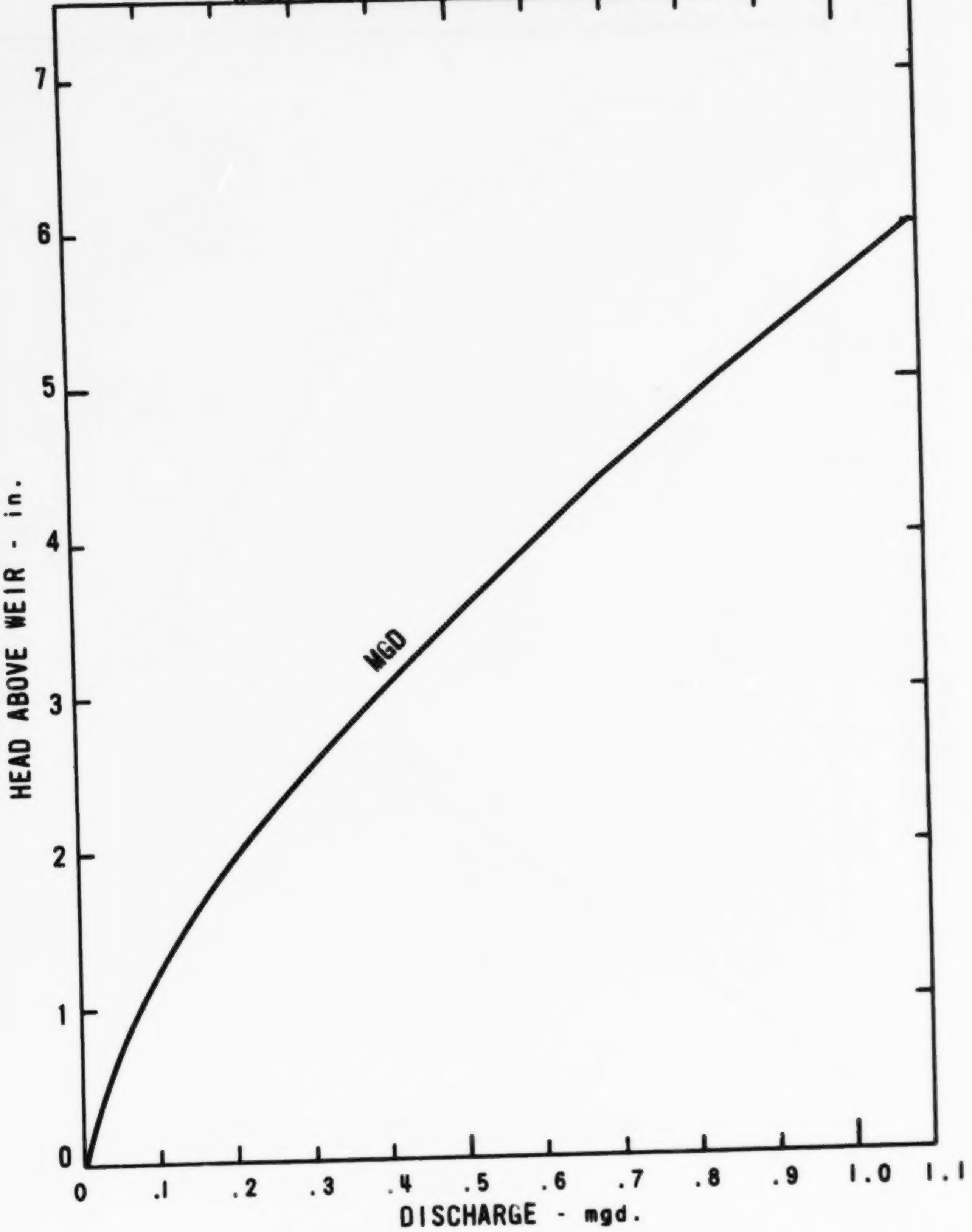


FIGURE 99 STAGE DISCHARGE CURVE
TROUT RUN SANITARY SEWER -12" DIA.

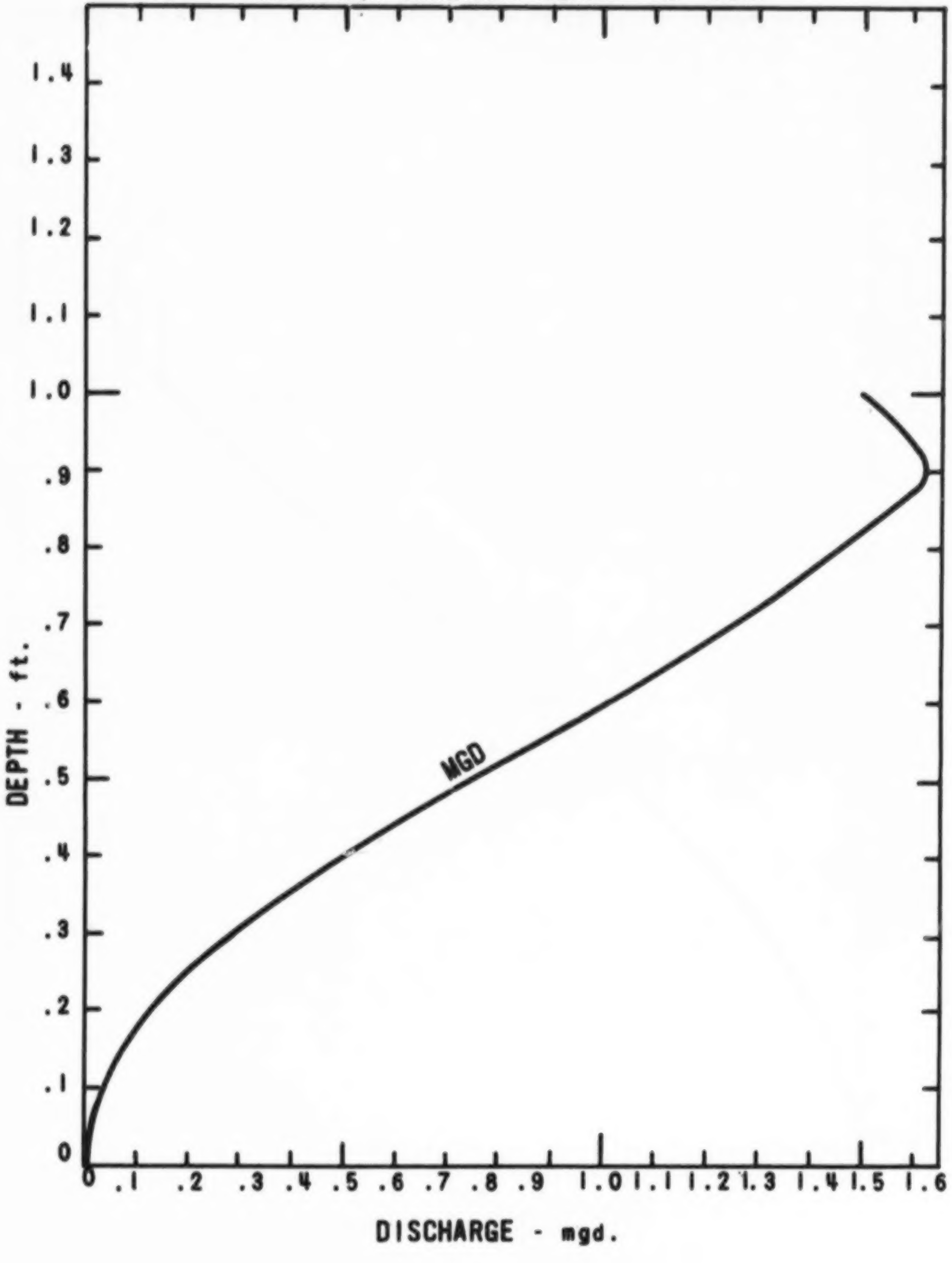


FIGURE 100 STAGE DISCHARGE CURVE
24th STREET SANITARY SEWER 15" DIA.

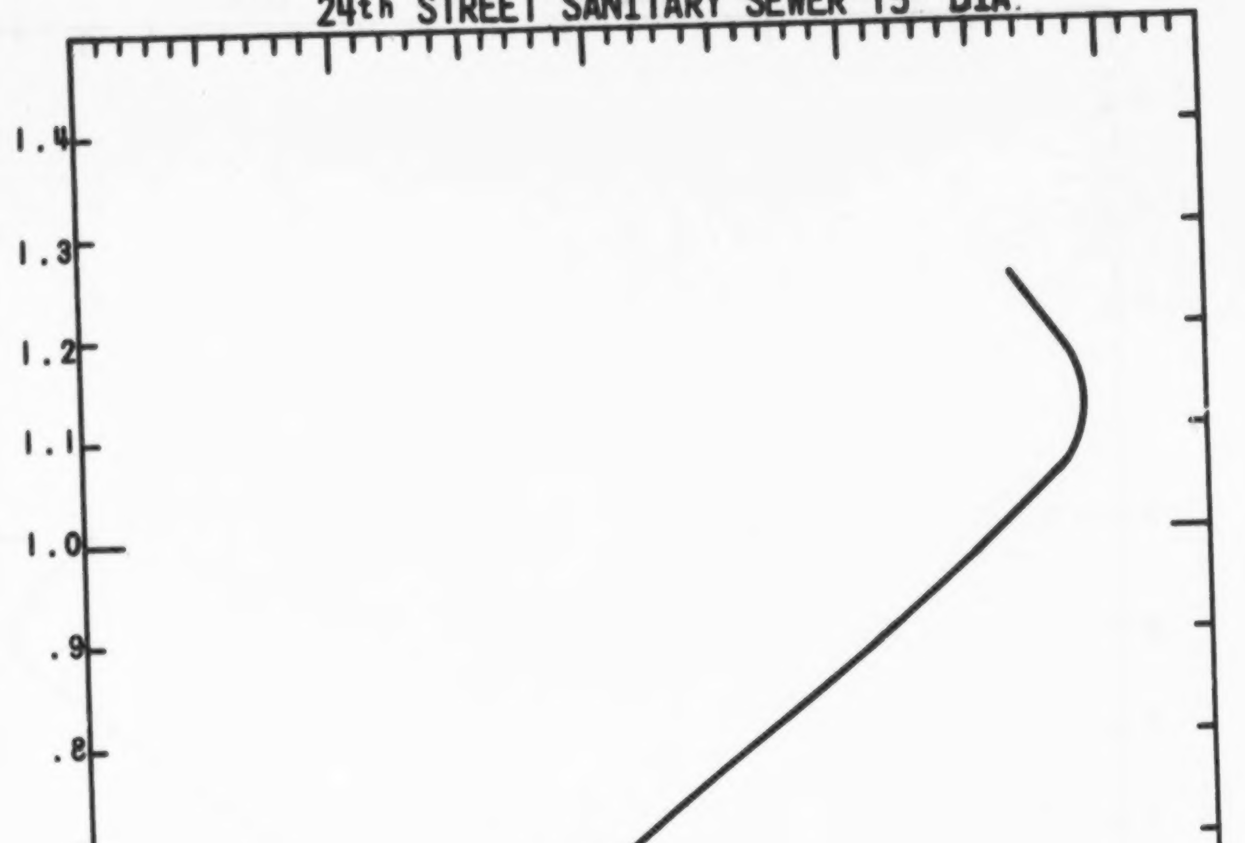
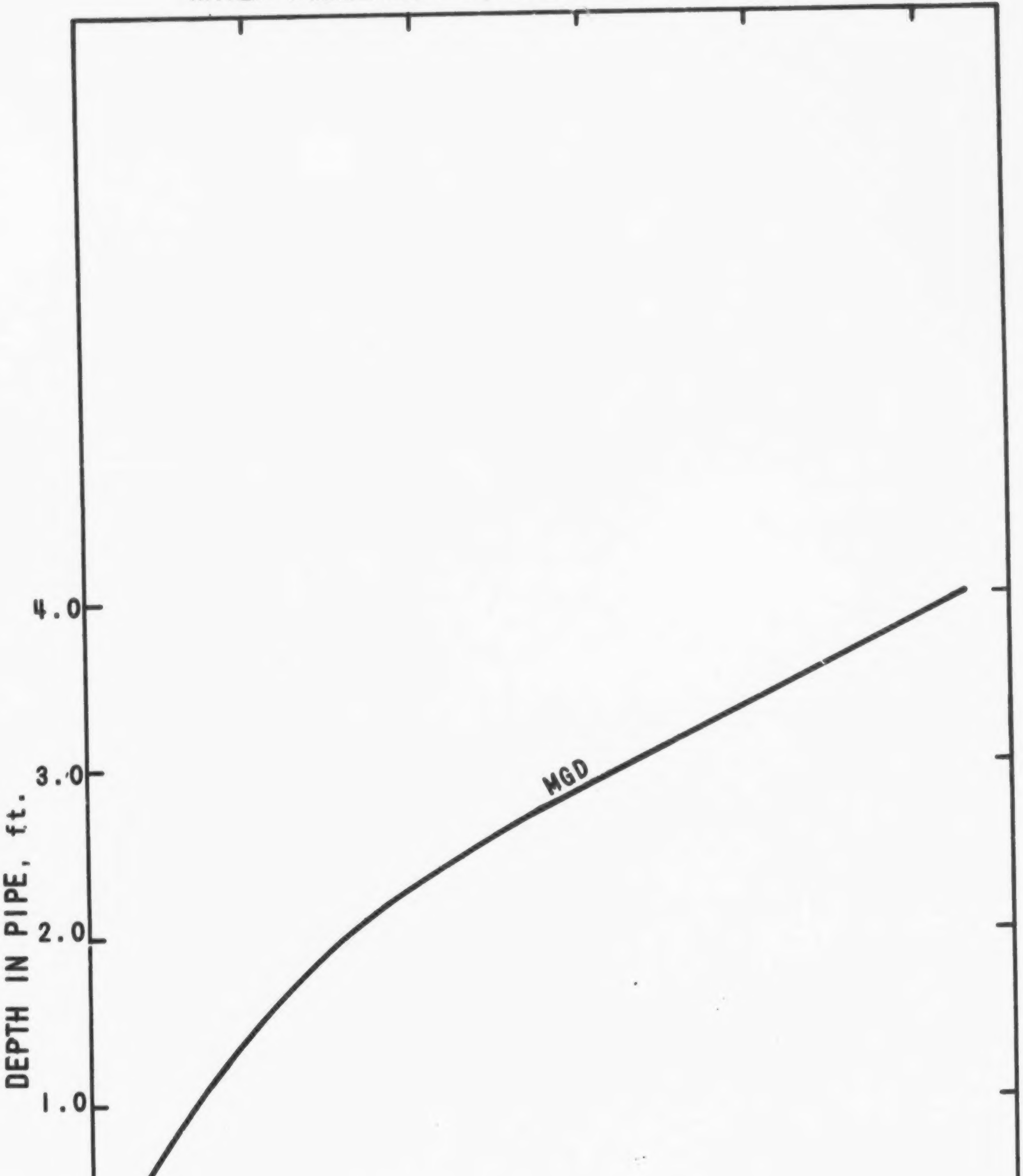


FIGURE 101 STAGE DISCHARGE CURVE
WATER POLLUTION CONTROL PLANT 54" DIAMETER



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APPENDIX VII

SAMPLING DATA FOR STREAMS AND SANITARY SEWERS OF THE THREE STUDY AREAS AND THE WATER POLLUTION CONTROL PLANT

TABLES 51 THROUGH 60

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TABLE 51

STREAM SAMPLING DATA

MURRAY RUN STREAM

Sample Date	Time	Flow (mgd)	BOD (mg./1.)	Total Solids (mg./1.)	Total Volatile Solids (mg./1.)	Suspended Solids (mg./1.)	Suspended Solids Volatile (mg./1.)	Settleable Solids (ml./1.)	Coliform MPN per 100 ml. (thousands)
6 Feb 1969	6:00 PM	6.0	13	367	116	133	38	1	15
	7:00 PM	6.5	14	296	109	80	24	1	4
	8:00 PM	7.2	13	771	127	303	93	5	46
	12:00 PM	6.0	26	720	213	93	38	2	2
8 Feb 1969	3:50 PM	5.6	7	342	124	60	21	1	46
	5:12 PM	6.0	2	263	61	33	8	1	46
	6:00 PM	7.5	11	305	87	33	10	1	15
	6:40 PM	9.0	3	290	75	27	7	1	4
24 Mar 1969	10:12 AM	10.0	11	340	92	37	9	2	240
	10:42 AM	9.9	14	828	177	90	19	5	240
	11:12 AM	9.5	21	2677	290	147	15	8	240
	11:42 AM	9.3	66	543	130	53	12	3	93
	12:27 PM	8.9	16	358	142	67	25	1	240

TABLE 52

STREAM SAMPLING DATA

TROUT RUN STREAM

Sample Date	Time	Flow (mgd)	BOD (mg./l.)	Total Solids (mg./l.)	Total Volatile Solids (mg./l.)	Suspended Solids (mg./l.)	Suspended Solids Volatile (mg./l.)	Settleable Solids (ml./l.)	Coliform MPN per 100 ml. (thousands)
6 Feb 1969	6:55 PM	6.2	20	488	200	213	79	5	110
	7:50 PM	4.7	10	273	122	70	26	1	110
	8:50 PM	2.9	7	208	55	37	9	1	110
	9:50 PM	2.0	4	213	67	43	13	1	24
8 Feb 1969	3:40 PM	1.8	18	607	169	167	46	3	24
	4:10 PM	4.9	13	719	196	160	42	3	46
	5:10 PM	3.2	16	422	127	117	35	2	46
	6:10 PM	8.9	8	445	140	110	34	2	46
24 Mar 1969	8:45 AM	13.0	31	393	146	77	33	2	11,000
	9:40 AM	9.5	25	403	206	100	51	2	11,000
	10:45 AM	7.5	23	361	115	90	30	3	11,000
	12:40 PM	5.0	29	277	127	70	31	1	11,000
23 Jul 1969	12:01 AM	78.0	22	745	175	97	22	4	5400
	12:20 AM	35.0	12	745	134	110	20	2	2400
	12:40 AM	16.0	13	531	115	100	21	6	5400
	1:00 AM	5.0	20	476	97	127	25	2	16,000
	1:20 AM	3.5	36	456	131	80	23	2	2400
	2:20 AM	2.0	31	612	207	67	22	8	3500
3 Aug 1969	5:28 PM	10.0	17	919	278	93	27	4	1100
	5:44 PM	45.0	20	492	139	107	29	2	2800
	5:59 PM	14.0	9	296	72	57	13	1	700
	6:45 PM	34.0	23	321	108	27	8	2	490
	7:45 PM	5.0	14	186	76	30	12	1	9200

TABLE 53

STREAM SAMPLING DATA

24TH STREET STREAM

Sample Date	Time	Flow (mgd)	BOD (mg./l.)	Total Solids (mg./l.)	Total Volatile Solids (mg./l.)	Suspended Solids (mg./l.)	Suspended Solids Volatile (mg./l.)	Settleable Solids (ml./l.)	Coliform MPN per 100 ml. (thousands)
6 Feb 1969	6:20 PM	0.3	39	705	193	153	46	3	110
	7:20 PM	2.2	22	653	179	163	43	3	46
	8:20 PM	1.8	8	345	126	97	31	1	110
	9:20 PM	1.2	23	379	132	87	30	2	24
	10:15 PM	1.0	5	209	98	73	31	1	24
8 Feb 1969	4:45 PM	2.8	45	1045	388	167	61	7	110
	5:45 PM	3.2	35	629	230	150	53	4	110
	6:45 PM	4.0	42	648	276	107	44	4	110
24 Mar 1969	8:30 AM	7.5	4	580	137	87	20	2	21
	9:25 AM	7.5	4	440	121	63	15	1	9
	10:25 AM	6.0	7	298	94	57	19	1	4
	12:30 PM	3.3	5	240	92	37	14	1	46

TABLE 54

SANITARY SEWER SAMPLING DATA

MURRAY RUN SANITARY SEWER

Sample Date	Time	Flow (mgd)	BOD (mg./1.)	Total Solids (mg./1.)	Total Volatile Solids (mg./1.)	Suspended Solids (mg./1.)	Suspended Solids Volatile (mg./1.)	Settleable Solids (ml./1.)	Coliform MPN per 100 ml. (thousands)
6 Feb 1969	6:10 PM	1.3*	156	550	267	136	61	8	140**
	7:10 PM	1.3*	90	302	41	37	5	0	140**
	8:10 PM	1.3*	96	298	104	83	27	0	140**
	12:10 AM	1.3*	66	304	100	73	23	4	140**
8 Feb 1969	3:50 PM	1.3*	140	705	284	427	180	1	1100**
	5:12 PM	1.3*	96	571	240	410	168	6	1100**
	6:00 PM	1.3*	252	1345	953	137	11	9	1100**
	6:40 PM	1.3*	92	450	212	113	52	11	1100**
24 Mar 1969	10:12 AM	1.3*	420	1225	845	70	47	42	11,000**
	10:42 AM	1.3*	114	513	286	57	31	11	11,000**
	11:12 AM	1.3*	114	509	221	137	53	27	11,000**
	11:42 AM	1.3*	108	524	296	97	56	35	11,000**
	12:27 AM	1.3*	192	418	229	77	43	17	11,000**

* Sewer surcharged - flow indicated is sewer capacity.

**Represents a minimum value - a more accurate choice of sample dilutions could have resulted in higher values.

TABLE 55

SANITARY SEWER SAMPLING DATA

TROUT RUN SANITARY SEWER

Sample Date	Time	Flow (mgd)	BOD (mg./l.)	Total Solids (mg./l.)	Total Volatile Solids (mg./l.)	Suspended Solids (mg./l.)	Suspended Solids Volatile (mg./l.)	Settleable Solids (ml./l.)	Coliform MPN per 100 ml. (thousands)
6 Feb 1969	6:50 PM	*	204	771	459	210	119	11	1100
	7:50 PM	*	150	845	508	130	80	19	1100
	8:50 PM	*	162	658	341	157	75	13	1100
	9:50 PM	*	108	537	324	280	171	8	1100
8 Feb 1969	3:40 PM	*	162	774	332	110	46	8	1100
	4:10 PM	*	168	832	342	130	51	9	1100
	5:10 PM	*	137	746	315	133	55	7	1100
	6:10 PM	*	168	711	311	120	51	7	1100
24 Mar 1969	8:45 AM	*	414	853	535	173	102	13	11,000***
	9:40 AM	*	174	581	321	130	70	12	11,000***
	10:45 AM	*	294	1021	599	177	100	24	11,000***
	12:40 PM	*	216	611	259	100	41	6	11,000***
23 July 1969	1:20 AM	1.5**	315	1269	660	123	61	17	54,000
	2:25 AM	1.5**	108	2624	2269	63	55	3	7900
3 Aug 1969	5:30 PM	1.0	600	1192	628	147	76	19	35,000
	5:45 PM	1.5**	405	1212	676	167	92	26	54,000
	6:00 PM	1.5**	360	1254	642	180	92	21	35,000

* Data not available.

** Sewer surcharged - flow indicated is sewer capacity.

***Represents a minimum value - a more accurate choice of sample dilutions could have resulted in higher values.

TABLE 56

SANITARY SEWER SAMPLING DATA

24TH STREET SANITARY SEWER

Sample Date	Time	Flow (mgd)	BOD (mg./1.)	Total Solids (mg./1.)	Total Volatile Solids (mg./1.)	Suspended Solids (mg./1.)	Suspended Solids Volatile (mg./1.)	Settleable Solids (ml./1.)	Coliform MPN per 100 ml. (thousands)
6 Feb 1969	6:30 PM	0.8	102	235	39	40	6	7	1100
	7:30 PM	0.8	98	410	240	37	17	5	1100
	8:30 PM	1.0	162	443	246	50	23	6	1100
	9:30 PM	1.0	144	417	211	37	17	3	1100
	10:15 PM	1.0	120	394	178	93	44	4	1100
8 Feb 1969	4:45 PM	1.0	102	504	225	70	30	9	1100
	5:45 PM	1.0	140	501	251	50	24	9	1100
	6:45 PM	1.0	88	320	141	40	17	5	1100
24 Mar 1969	8:30 AM	1.6	324	405	242	47	27	6	11,000*
	9:25 AM	1.7	150	497	295	67	39	9	11,000*
	10:25 AM	1.7	156	432	203	50	25	5	11,000*
	12:30 PM	1.5	144	433	194	33	13	3	11,000*

*Represents a minimum value - a more accurate choice of sample dilutions could have resulted in higher values.

TABLE 57

SAMPLING DATA

WATER POLLUTION CONTROL PLANT OVERFLOW

Sample Date	Time	Flow (mgd)	BOD (mg./l.)	Total Solids (mg./l.)	Total Volatile Solids (mg./l.)	Suspended Solids (mg./l.)	Suspended Solids Volatile (mg./l.)	Settleable Solids (ml./l.)	Coliform MPN per 100 ml. (thousands)
23 July 1969	1:30 AM	7.2	203	941	562	137	80	12	160,000
	1:45 AM	7.5	192	794	428	120	64	11	92,000
	2:00 AM	7.6	218	894	438	170	83	16	35,000
	2:15 AM	7.6	212	870	449	117	57	16	35,000
	2:30 AM	7.4	239	978	524	127	63	25	17,000
	2:45 AM	7.1	293	1086	567	130	65	27	24,000
	3:00 AM	6.6	276	1074	570	103	52	30	35,000
	3:15 AM	4.2	276	1100	565	100	50	31	11,000

TABLE 58

SAMPLING DATA

ROANOKE RIVER INTERCEPTOR ABOVE PLANT

Sample Date	Time	Flow (mgd)	BOD (mg./l.)	Total Solids (mg./l.)	Total Volatile Solids (mg./l.)	Suspended Solids (mg./l.)	Suspended Solids Volatile (mg./l.)	Settleable Solids (ml./l.)	Coliform MPN per 100 ml. (thousands)
23 July 1969	2:00 AM	*	145	778	438	83	46	6	92,000
	2:50 AM	*	84	587	235	73	29	6	54,000
3 Aug 1969	6:25 PM	17.5	108	609	331	37	19	6	35,000

*Data not available.

TABLE 59

SAMPLING DATA

SANITARY SEWER DRY WEATHER FLOW

24 HOUR COMPOSITE

Location	Date	Flow (mgd)	BOD (mg./1.)	Total Solids (mg./1.)	Total Volatile Solids (mg./1.)	Suspended Solids (mg./1.)	Suspended Solids Volatile (mg./1.)	Settleable Solids (ml./1.)
Murray Run	19 Feb 1969	0.32	181	476	241	91	40	9
24th Street	16 July 1969	0.69	192	616	325	113	53	6
Trout Run	16 July 1969	0.86	342	890	473	200	98	8

TABLE 60

SAMPLING DATA

STREAM DRY WEATHER FLOW

24 HOUR COMPOSITE

Location	Date	Flow (mgd)	BOD (mg./1.)	Total Solids (mg./1.)	Total Volatile Solids (mg./1.)	Suspended Solids (mg./1.)	Suspended Solids Volatile (mg./1.)	Settleable Solids (ml./1.)
Murray Run	17 Sep 1969	4.0	8	248	85	37	12	0
24th Street	1 May 1969	1.2	8	194	126	20	7	0
Trout Run	1 May 1969	1.0	3	281	147	17	8	0

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APPENDIX VIII

SUMMARY REPORT OF LITERATURE SEARCH

PURPOSE

The purpose of this report is to present a summary of literature related to phases of this project, to support preliminary design criteria.

SCOPE

This report includes a brief summary of all literature and knowledge found to be pertinent and having important features of direct bearing on the following:

1. Field investigation
2. Hydrological investigation
3. Monitoring and sampling
4. Analysis
5. Remedial measures for sanitary sewage overflows

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FIELD INVESTIGATION

Larmon (1) [2] reports that the City of South Charleston, West Virginia used smoke testing to enforce an ordinance banning the connection of downspouts to sanitary sewers. Equipment consisted of the following:

1. Portable 1500 cfm Homelite blower
2. Sheet of 3/4-inch plywood
3. Canvas air duct
4. Sponge rubber

The plywood was lined with the sponge rubber to ensure a sealed fit over open manholes. Smoke was introduced by inserting a smoke bomb into the suction side of the blower. All violations and apparent breaks or leaks in the sewer were marked for future repair.

Can Tex Industries, Inc. of Cannelton, Indiana suggests the following for conducting smoke tests. Equipment should consist of:

1. One minute smoke bombs
2. Small blower
3. Test tee
4. Sewer plug

Insert the test tee in the house line, using the plug on the sewer side of the house connection. After insertion of a lighted smoke bomb into the blower, watch for smoke to appear at ground level or somewhere around the house foundation or downspouts. Further emphasis is placed on the notification of the area residents of the intended plan of smoke testing.

The National Clay Pipe Institute supplied information concerning the smoke testing of sewers. Their advice concerned primarily the correct procedure to follow and the violations that may be encountered.

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[2] Numerals in parentheses refer to corresponding items at the end of this appendix.

The City of Roanoke's smoke testing crew also provided helpful information, in that they had been smoke testing in the city since spring of 1968.

A study conducted by Hayes, Seay, Mattern & Mattern in 1965 on the sanitary sewers in Roanoke revealed important data concerning the condition of the sewers and trouble spots that develop during heavy rainfalls.

HYDROLOGICAL INVESTIGATION

Greely and Langdon (2) used a rational approach relating rainfall to sewage quantities and tributary areas in a study of storm water and combined sewage overflows near East River of Long Island Sound. Hourly records of rainfall for five summer months and over the 8-year period from 1950 to 1957 were obtained. The data were tabulated and analyzed to establish the number of storms, the total rainfall in the storm and the duration of the storm. Based upon certain assumptions the data were translated into a rational analysis of the amount, number and frequency of overflows.

Benjes, Haney, Schmidt and Yarabeck (3), in a study of storm-water overflows from combined sewers in Kansas City, Missouri, reported that runoff of 1 x dry weather flow (DWF) or greater will occur 3.6 percent of the time and that runoff of 2 x DWF or greater will occur 3.2 percent of the time. In arriving at these conclusions, the frequency of occurence of various rainfall intensities was determined by counting the number of hours during which each intensite occurred. Measureable rainfall occurs only about 5 percent of the time at Kansas City. Rainstorms producing runoff occur only about 3.7 percent of the time. The data selected for analysis were the official published records of the U. S. Weather Bureau titled "Hourly Precipitation" for the Municipal Airport Station, Kansas City, Missouri.

McKee (4) made a detailed study of low-intensity storms using Boston records for the June through November period for 1934 to 1945. He found that a rainstorm of 0.04 in./hr. will produce storm runoff equal to DWF and that 0.03 inch is necessary to wet down the area before runoff begins. Thus, in Boston, a rainstorm of 0.01 in./hr. after initial wet-down, will produce runoff equal to DWF.

The Corps of Engineers, in 1965, published a report pertaining to flooding of downtown Roanoke from waters of Lick Run. This report gives a complete breakdown of their analysis of rainfall and runoff in the Lick Run drainage area which is adjacent to the Trout Run drainage area used in this study.

The U. S. Weather Bureau has published a climatic summary for the State of Virginia. In this report a history of the total precipitation for Roanoke is given per month plus the mean number of days with precipitation between 0.10 and 0.50 inch as recorded at the local U. S. Weather Bureau at Woodrum Airport.

The Corps of Engineers, in a manual titled "Flood-Hydrograph Analyses and Computations", describe and illustrate certain methods of deriving fundamental hydrologic factors by analysing observed hydrographs of stream flow and related meteorological events and suggests methods of utilizing these deduced factors in computing hypothetical hydrographs of runoff for conditions differing, in specified respects, from those prevailing during the observed floods.

Dunbar and Henry (5) report the following results from a study in Concord, N. H. during the summer months from 16 June through 15 September for the 10-year period 1949 through 1958. Of the 191 storms that occurred during the 10 summers, all produced runoff sufficient to cause overflows from interceptors designed for 3 x DWF. The average frequency was 6.4 times per month and the total average rainfall was 3.03 in./month. The average rainfall that produced runoff after wetting was 93 percent of the average monthly rainfall or 2.83 in./month. The average dry weather flow of sanitary sewage at its equivalent of 0.01 in./hr. of rainfall is equivalent to 7.2 in./month. Thus the total amount of stormwater runoff for Concord is only about 40 percent of the total sanitary sewage.

MONITORING AND SAMPLING

Burm, Krawczyk and Harlow (6), in a study in 1965 to determine and compare the chemical and physical qualities of the effluents discharged from combined and separate storm sewers in the Detroit-Ann Arbor area, used automatic samplers to obtain their samples. The equipment consisted of submersible pumps which lifted the sample out of the sewer to an automatic sampling mechanism. The sampling bottles used were one quart bottles situated on a rotating turntable actuated by a timing mechanism. Samples were taken at five minute intervals at

Ann Arbor and one hour intervals at the Detroit installation. Methods of measuring heads in the sewers were incorporated into each site, but flow calibrations of the sewers were extremely difficult because of the large discharges involved, as well as the rapidly fluctuating flows.

Cruchley (7) reports that the Road Research Laboratory used a new instrument during investigation on surface water drainage to record flow in sewers. The device records variations with time in the rate of sewage flow and the periods of time during which the flow is in excess of certain values selected for a particular study. The instrument is composed of a movement recorder and a time totalizer, the latter consisting of a time base and multiple-contact switch-unit within the movement recorder and a separate box containing a rectifier and a battery of counters.

Ellis and Johnston (8) report on a field method of measuring and recording flow in sewers. The size, length and slope of a sewer between two manholes must be determined. For known depths of flow in a sewer, determine velocities between the upper and lower manholes by using dye test and stop watch. From the velocity data determine the roughness coefficient "n" through the Manning formula. Prepare a depth-discharge curve for the particular stretch of sewer. Using a stage recorder, continuously record the depth of flow in the sewer for the desired period, and convert the depth data to flow rate.

Fathmann (9) reports on methods and equipment for the measurement of sewage flow. To obtain quantitative measurements within a definite given time, tank measurements are employed, using floats and measuring weirs. Stationary calculations on volume of sewage are carried out by measurements in pressure pipe lines according to the Venturi principal or as inductive measurements for the rate of flow.

Weidner, Weibel and Robeck (10) describe a method of sampling and gaging using an automatic mobile unit. The unit will sample stormwater runoff from various environments on a time-proportioned or flow-proportioned basis. The operation of a sampler is dependent on a sufficient amount of rainfall to start the electrical and cooling systems and predetermined amount of runoff to activate the sampling section.

In a study of urban runoff in Cincinnati, Weibel, Anderson and Woodward (11) report that the stormwater flows were measured with a 4-foot rectangular weir and a continuous water level recorder with 24-hour chart. Flows up to 25 cfs could be measured with such a set up. Samples were collected by means of suction hose and small battery operated centrifugal pump located at a manhole, which was 50 feet upstream of the outfall. The pump discharged to a revolving distributor and 36 4-liter polyethelene bottles arranged in a housing unit. The pump was actuated by a float device. The distributing arm rotates constantly, powered by a spring motor, passing over vertical tubes arranged in a circle and connected by hoses to the individual bottles. The arm takes 10 minutes to pass from the center of one tube to the next, flowing continuously. Plastic bottles with special glass tubing inlets and aluminum foil caps collect samples for bacteriological analyses.

ANALYSIS

Greely and Langdon (2) found that the interception and treatment of the dry weather flow and the first flushings of storm water will reduce the volume of sewage discharged through overflows to about 3 percent of the total sewage flow. With complete treatment of the intercepted flow, about 90 percent of the BOD can be removed. Treatment of intermittent discharges from overflows by retention and chlorination to remove floating solids and bacterial contamination can also improve conditions in receiving streams.

Camp (12) reports that the average dry weather flow of sanitary sewage from combined sewerage systems is approximately equal to the runoff from a rainstorm having an intensity of about 0.01 in./hr. For interceptors having a capacity of 2 x DWF, more than 90 percent of the sanitary sewage is discharged in the overflows with a rainfall intensity of 0.2 in./hr. or more. With interceptors having a capacity of 5 x DWF, about 76 percent of the sanitary sewage is lost during rainstorms having an intensity of 0.2 in./hr. and about 90 percent is lost during rainstorms having intensity of 0.5 in./hr.

Burm, Krawczyk and Harlow (6), in a comparative study of separate storm-sewer discharges in Ann Arbor, Michigan, with combined discharges in Detroit, showed that the BOD in the separate storm sewer discharges was about 20 percent of that in the combined discharges. Concentrations lessened as discharges increased. Values for total and volatile suspended solids and for total and volatile setteable solids were higher in the separate storm sewerage system because of greater erosion in hillier terrain. Phosphates were higher in combined flows, but nitrates were lower. In the separate system, BOD was fairly constant throughout the year, but in the combined system, summer BOD values were higher.

Weibel, Anderson and Woodward (11) in a field study of sewered storm water runoff in Cincinnati, noted the following results: the BOD and suspended solids discharged increased with increasing size of storm; there was little seasonal change in constituent means concentration, except for BOD and for high chlorides in winter snow melt; and the suspended solids and volatile suspended solids discharges were roughly comparable to dustfall and combustibles in dustfall for the year, measured at a city air pollution sampling station in the area. Several of the stormwater runoff constituents discharged over the year were compared with the computed amounts of the same constituents that might occur in the raw sanitary sewage produced in the area, all on a pounds-per-acre-per-year basis, by using the 9 person-per-acre population density of the watershed. The comparisons of stormwater runoff to raw sewage on a percentage basis are: suspended solids from stormwater runoff, 140 percent of raw sewage production; volatile suspended solids, 44 percent; COD, 25 percent; BOD 6 percent. It was concluded that urban storm runoff cannot be neglected in considering waste loadings from urban sources and that information from a variety of runoff environments is needed.

Weibel, Weidner and Christianson (13) report on results of a study at Cincinnati on the polluting effect of storm water run-off from urban areas. The rain water was found to contain, on an average, 0.69 mg of inorganic nitrogen and 0.24 mg of hydrolysable phosphate per litre; these concentrations exceed the threshold values found by others for the development of algal blooms. Analyses of the run-off showed its pollution potential, and the concentrations of coliform organisms exceeded the criterion of 1000 per 100 ml recommended for bathing waters. Sedimentation alone was not effective in reducing BOD and suspended solids content. Sedimentation for 20 minutes combined with chlorination at a dose of 4.62 mg of chlorine per litre killed more than 99 percent of the bacteria; when the supernatant liquor was dechlorinated, however, and kept at room temperature for 24 to 72 hours, there was aftergrowth of coliform organisms, though not of fecal coliform bacteria.

Palmer (14) discusses the effects of pollution caused by overflowing of storm water from combined sewers in Detroit. Runoff did not occur unless precipitation was greater than 0.03 in./hr. and storm water would not overflow unless precipitation was more than 0.03 in./hr. plus the capacity of the sewers for storm water. Intercepting sewers were most effective in preventing overflow when their capacity was 150 percent of the sewage flow and no satisfactory reduction in number or duration of overflows was achieved by increasing the capacity to any reasonable extent. The quality of the overflowing liquid varied considerably and would be highly polluting even from a separate system.

Weller and Nelson (15) report on the findings of a study in Kansas City, Missouri concerning stormwater infiltration into sanitary sewers. During periods of moderate precipitation the major portions of the flow are from sources other than the water-using plumbing fixtures in the residences and public buildings within the district. During these periods the major source of sewer flow is ground water, presumably from foundation drains used throughout the district.

REMEDIAL MEASURES

Weller and Nelson (16) report on steps taken to divert and treat peak flows in Johnson County, Kansas and Kansas City, Missouri. They state that in these two areas the maximal flows may be many times the average as a result of extraneous flows, defined as liquids entering the sanitary sewers through sources other than plumbing fixtures or process facilities. The peak flows are settled, skimmed and chlorinated before discharge, thus reducing possible pollution of the receiving stream.

Rhodes (17) reports that, in Montgomery County, Dayton, Ohio, a number of attempts were made to correct the infiltration into a newly constructed sewerage system. Before any customers were connected the lines were carrying almost plant capacity due to infiltration. Spot checks of the system by closed-circuit television in 1962 indicated that the "poured joints" were allowing the greatest quantity of infiltration. The remedial methods attempted were:

1. Relaying of one mile of trunk sewer. This proved to be to costly.
2. The joints of a short section of line were uncovered and a concrete collar was poured around them. This also proved to be too costly.
3. Plastic liners were placed inside the sewer lines. The cost of the liners was not prohibitive but the reduction in line capacity could not be afforded.
4. Television inspection and sealing with polymer-type grouting fluid.

The method that proved successful was inspection by television to pinpoint leaks and sealing with a polymer-type grouting fluid called PWG. The number of leaks repaired in this manner averaged 7 leaks per 300 feet of sewer line.

Metz (18) describes a procedure for reducing infiltration by remote control grouting. The equipment required in the process includes a van-type truck, chemical grout mixing and pumping equipment, sewer grouting packers and plugs, air compressor, television inspection components, winches, down-hold sheaves and communication system. A winch cable, to which is attached a television camera and sewer grouting packer, is pulled through the sewer line. The trailing winch line is attached to the grouting packer, and a communication line is placed between the two winches and the grouting engineer. The inline equipment is then moved through the sewer. When a leak is observed on the television monitor, the grouting packer is set over the leak and sufficient chemical grout is pumped through the set packer to seal the leak.

Godbehere (19) describes a method used in Amersham, England to reduce infiltration. The sealant is Terraseal which is a form of sodium alginate. It can be delivered to the site bagged as a coarse brown powder for mixing with water or as a concentrated viscous solution in drums for dilution before use. In Amersham, Terraseal was mixed on site in a 500-gallon tank, agitated and heated to produce a suitable solution. The prepared solution was transferred to a 100-gallon gauging tank and pumped into the head of the first length of sewer previously stoppered at the downstream end. When full the head was then stoppered and couplings completed to the reciprocating pump. The solution was then pumped under pressure and the loss through faults into the ground monitored by measurement of the depth in the gauging tank. Further investigation showed that the procedure improved the line by eliminating about 95 percent of the infiltration in the section of line tested.

Crane (20) reports on a plan by Buffalo, New York to prevent flooding from overloaded storm sewers by storing excess storm water in a disused quarry which has a capacity of 2,350,000 cu. ft. The water will then be pumped gradually into the sewers and so discharged into the creek.

Waller (21) reports on the design and operation of one of two retantion tanks constructed to prevent overflows into Halifax harbor from the "Arm sewer", an interceptor sewer which drains the west and northwest sections of Halifax, Nova Scotia. The tank, which has a capacity of 1 million gallons, is provided with an aerated detritus tank through which dry-weather flow passes directly to the interceptor sewer after screening; but when flow in the sewer reaches a maximal level, passage through the detritus tank is stopped, and the retention tank fills, providing 15-minute detention at a design peak flow of 150 cu. ft. per second before over-flowing to the "Arm sewer". Arrangements are made for chlorination to continue as long as the rate of inflow exceeds the rate of outflow to the interceptor. If the intensity and duration of the storm are sufficient to fill the tank, the chlorinated sewage is discharged to the harbor.

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Results are given of investigations, on 25 percent of Roanoke, Virginia's separate sanitary sewerage system, on the amounts of infiltration for various storm intensities and durations and the amounts of sewage overflow from the system. From these results the system was analyzed, using an in-house developed computer program, to assess the magnitudes and frequencies of overflows. The generated data from the analysis were used to develop an optimum design for remedial measures to reduce sewer overflows. Costs estimates are presented for the various items of work involved.

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